TP 4435 E

DETECTION AND AVOIDANCE OF HAZARDOUS ICE CONDITIONS AT SEA - A REVIEW OF R & D ACTIVITIES IN CANADA

March 1983

NORDCO LTD., P. O. BOX 8833, ST. JOHN'S, NEWFOUNDLAND, A1B 3T2

The contents of this report reflect the views of the contractor, and not necessarily the official views or policies of the Transportation Development Centre, Transport Canada

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 4435 E	4865	NIL

4. Title and Subtitle	5. Report Date
Detection and Avoidance of Hazardous Ice Conditions at Sea - A Review of R & D Activities in Canada	31 March 1983
	6. Performing Organization Report No. 176-82G
7. Author(s) R.A. Stacey	8. Transport Canada File No. D1460-146-5
9. Performing Organization Name and Address Nordco Limited P.O. Box 8833, St. John's Newfoundland A1B 3T2	10. DSS File No. NIL
	11. DSS or Transport Canada Contract No. 4865
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 1000 Sherbrooke St. West Suite 2421, Montreal, P.Q. H3A 2R3	13. Type of Report and Period Covered Nov. 1982 to March 1983
	14. Sponsoring Agency Code
15. Supplementary Notes NIL	16. TDC Project Officer Maurice Audette

17. Abstract

Ice hazardous to navigation is of concern to all shipping and off-shore drilling operations in the Arctic and off the east coast of Canada. Information on current ice hazard detection/avoidance research gained through questionnaires and personal interviews is compared with present and possible future requirements for Arctic shipping, and hydrocarbon developments on the Grand Banks, off Labrador and in the Beaufort Sea. It is concluded that development of a computerized, multi-sensor ice detection/avoidance system is technologically possible, but cannot be justified in the absence of a clear understanding of the capabilities of different remote sensing techniques. It is recommended that TDC sponsor a technical workshop on shore and ship-based ice sensing systems involving researchers and those with operational requirements. Evaluation and development of individual sensors is also recommended, as any integrated, multi-sensor system would have to be tailored to particular operating requirements.

18. Key Words	19. Distribution Statement
Shipping, Navigation, Remote Sensing, Sea Ice Detection, Off-shore oil drilling.	Limited number of copies available from sponsoring agency

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
NIL	NIL	26 + App.	NIL

TDC/CDT 79-005

FORMULE DE DOCUMENTATION POUR RAPPORT

1. Nº du rapport Transports Canada	2. Nº de l'étude — CDT	3. Nº de catalogue du destinataire
TP 4435E	4865	NIL

4. Titre et sous-titre	5. Date du rapport
Detection and Avoidance of Hazardous Ice Conditions at Sea - A Review of R & D Activities in Canada	le 31 mars 1983
	6. Nº du rapport de l'organisme exécutant: 176-82G
7. Auteur(s): R.A. Stacey	8. Nº de dossier Transports Canada: D1460-146-5
9. Nom et adresse de l'organisme exécutant: NORDCO Limited, P.O. Box 8833, St. John's, Newfoundland, A1B 3T2	10. Nº de dossier — ASC: NIL
	11. Nº de contrat — ASC ou Transports Canada: 4865
12. Nom et adresse de l'organisme parrain: Centre de développement des transports, 1000 Sherbrooke ouest, Suite 2421, Montréal, P.Q. H3A 2R3	13. Genre de rapport et période visée: Nov. 1982 à mars 1983
	14. Code de l'organisme parrain
15. Remarques additionnelles: NIL	16. Agent de projet — CDT: Maurice Audette

17. Résumé

Les glaces flottantes constituent un danger pour la navigation maritime et les travaux de forage sous-marin dans les régions arctiques et le long du littoral Est du Canada. Le présent rapport fait le point sur l'état actuel des connaissances en matière de détection et d'évitement des glaces flottantes, obtenu grâce à des questionnaires et des interviews personnelles. Il les confronte aux exigences actuelles et prévisibles de la navigation dans les eaux arctiques et des installations de mise en valeur des gisements pétroliers au large des côtes du Labrador et dans la mer de Beaufort. Le rapport conclut que la réalisation d'un système informatisé, faisant appel à plusieurs types de détecteurs, est techniquement faisable, mais qu'il ne saurait être justifié tant que les différentes techniques pouvant être mises en oeuvre n'auront pas été étudiées à fond et maîtrisées. Il recommande de mettre sur pied un atelier d'étude des divers systèmes de détection, au sol et embarqués, qui réunirait chercheurs et utilisateurs éventuels. Il préconise en outre l'évaluation séparée des divers détecteurs et systèmes proposés afin d'en connaître les aptitudes exactes dans le but de permettre la réalisation de produits adaptés aux besoins spécifiques des utilisateurs.

18. Mots-clés	19. Diffusion
Navigation maritime. Forage sous-marin. Télédétection. Détection des glaces flottantes.	Nombre limité de copies disponibles auprès de l'organisme parrain

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
aucune	aucune	26 + app.	Nil

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
	1.1 Study Objectives	1
2.0	SEA ICE AND ICEBERG HAZARDS	3
	2.1 Sea Ice	3
	2.2 Icebergs	4
3.0	OPERATIONAL REQUIREMENTS FOR ICE DETECTION/AVOIDANCE	5
	3.1 Arctic Class Vessels	5
	3.2 Grand Banks Drilling Operations	6
	3.3 Labrador Sea Drilling Operations	7
	3.4 Beaufort Sea Drilling Operations	10
	3.5 Current Requirements and Priorities	11
4.0	CURRENT R & D PROGRAMS	16
	4.1 Review of Information From Questionnaires	16
	4.2 Evaluation of On-going R & D	19
5.0	TRANSPORTATION DEVELOPMENT CENTRE (TDC) INVOLVEMENT	23
	5.1 Past and Present TDC Activities	23
	5.2 Recommendations in TDC Involvement	24

REFERENCES

APPENDICES

Appendix I - Description of Current R & D Projects

Appendix II - World Meteorological Organization - Sea Ice and Iceberg Nomenclature

Appendix III - Government Regulations and Guidelines Releveant to Ice Detection/Avoidance

1.0 INTRODUCTION

Drilling activities in the Beaufort Sea and off the east coast of Canada, coupled with plans to move liquified natural gas (LNG) from the Arctic islands to southern ports by large, icebreaking vessels, have generated a need to develop a means of detecting glacial or sea ice likely to be a hazard to the vessels concerned. Over the past few years, a number of ice detection projects have been started, ranging from the development of an extremely bright light source, through basic research into the backscatter of sea ice at various radar frequencies, to an attempt to develop a fully integrated multi-sensor system. To date, there has been informal contact between the various groups, but it appears that no attempt has been made to keep track of evolving requirements for the various offshore operations, which range from anchored drilling vessels in the Beaufort Sea and on the Grand Banks, through dynamically positioned drilling vessels off Labrador, to very large, icebreaking vesels moving through the Northwest Passage throughout the year. Each operation has its own peculiar ice hazard situation, and even these vary depending on the detailed day-to-day nature of the operation and the time of year.

1.1 Study Objectives

The overall objective of the Transportation Development Centre (TDC) program is to develop a ship-mounted and computer-controlled ice hazard detection/collision avoidance system for more efficient and safe marine transportation in ice infested Arctic and northern waters. The specific objective of this report is to seek information on appropriate R & D activities services and to formulate recommendations on the R & D needed for the application of advanced electronics to ice hazard detection/collision avoidance.

Thus, this report is an attempt to review on-going R & D programs, both in government and industry, against a likely timetable for operational system requirements in the Arctic and off the east coast. Some research identified in this report is confidential to the companies concerned and can only be reported in general terms. Also

it must be appreciated that the time table of requirements is open to adjustment as plans are modified to accommodate economic and political factors beyond the scope of this report.

Following a general description of sea ice and iceberg features, an attempt is made to define the term "ice hazard" as it applies to Arctic Class vessels and to in the Beaufort Sea, Labrador Sea and Grand Banks areas where hydrocarbon drilling activities predominate.

For each type of activity an attempt is made to draw up an operational ice hazard detection performance specification, and a date by which the system should be operational. The specifications and, in particular, the date of the system will be required are open to discussion and continuing adjustment. However, they are the author's personal assessment based on discussions with those involved in the various activities.

Following this "statement of requirements" is a description of on-going R & D programs culminating in the author's evaluation of the overall effort in relation to the various "requirements". Again, the statements made will be open to discussion and amendment with time. However, they will serve as a focus for discussion and provide a vehicle for future R & D planning. This is followed by a brief review of TDC involvement to date.

In the final section, recommendations are made for a co-ordinated ice hazard detection system development program that recognizes the different requirements and, as far as possible, takes advantage of on-going operations for equipment evaluation. This approach, provided it is recognized that the R & D project must not interfere with on-going operations, will be the most cost-effective means of gaining experience with different sensors in various combinations.

2.0 SEA ICE AND ICEBERG HAZARDS

2.1 Sea Ice

Level, undisturbed first year sea ice can be up to 2 metres thick at the end of the winter in the Arctic, and up to 1 metre thick off the east cost. Wind, current, and thermal adjustment can cause the ice to break into floes ranging in size from metres to many kilometres. The open water leads between flows and the ridges of broken ice formed when the floes drift together, form linear features, often many kilometres long. Unfortunately, the angular edge of a lead, representing an easy passage, and the angular blocks of a ridge, which, depending on the degree of consolidation, can represent a hazard to shipping, cannot always be distinguished from one another by marine radar. Other features that can occur in first year ice are hummocks, caused by arching of unbroken ice under pressure, and rubble fields, where large areas of ice have been broken into random blocks under the influence of pressure. Both features produce an increase in the normal thickness of the ice and consequently can represent a hazard to shipping. The angular nature of the blocks in the fresh rubble fields are relatively easy to recognize using radar, but the rounded, low lying hummocks represent a much more difficult target as much of the radar energy is disbursed rather than returned to the antenna.

As the winter season progresses, salt migrates to the surface of the ice forming a highly saline layer and gradually altering the dielectric properties of the surface. In spring and summer, melt pools with varying salinity form on the surface of the ice which, assuming the ice is not destroyed completely during the summer months, refreezes as second or multi-year ice. The surface of this older ice is characterized by random hummocks separated by areas of level fresh water ice. During the melting and refreezing process, ridges can change from loosely connected ice blocks with a keel depth several times the height of the sail, to a solid wall. The expulsion of the salt and the refreezing process produces multi-year ice, which is much stronger than first year ice and, consequently, a much greater poten-

tial hazard to shipping. The "hummocky" surface sometimes produces a speckled radar image that permits the ship's master to recognize and avoid areas of harder multi-year ice.

2.2 Icebergs

The largest iceberg that might be encountered in the vicinity of the Hibernia oil field south east of St. John's is estimated to be 10^7 tonnes. Such an iceberg would be tabular in shape rising about 10 metres above the water with a draft of approximately 80 metres - the depth of water in the area. An iceberg of this size would be readily detectd by radar even under severe sea conditions, provided it had near vertical sides above the water line. However glacial ice occurs in a variety of shapes and sizes ranging from small bergy bits or growlers up to 50,000 tonnes, to large ice bergs weighing several million tonnes in the deep waters of Baffin Bay and beyond the continental shelf. In general, the ice is a poor radar reflector and experience on drill ships off Labrador indicates substantial icebergs can remain undetected by radar until they are within 10 km of the vessel. Similarly, experience indicates growlers and bergy bits are practically impossible to detect by radar during periods of high seas and poor atmospheric conditions, and may have actually collided with drill ships in the past.

The formal description of icebergs, as developed by the World Meteorological Organization (WMO), is provided in Appendix II.

3.0 OPERATIONAL REQUIREMENTS FOR ICE DETECTION/AVOIDANCE

An attempt has been made to identify operational requirements as they apply to Arctic class vessels, and to drilling operations on the Grand Banks, off the coast of Labrador, and in the Beaufort Sea. In the case of Arctic class vessels, government regulations specify certain minimum hazard detection capabilities, whereas for drilling operations, criteria have been developed that are a function of the nature of the drilling platform, and the period of time required to successfully complete each particular task associated with the drilling operation. From the ensuing discussion it will be clear that regulatory and drilling practise concentrates on detection and avoidance of ice, with little or no attempt to quantify the degree of hazard presented by different forms of sea ice and glacial ice.

3.1 Arctic Class Vessels

The structural standards, operating procedures, and the movement of ice breaking, "Arctic Class" vessels in Canadian waters are governed by the Arctic Waters Pollution Prevention Act. The "class" of a vessel can range from 1 to 10, each class roughly corresponding to the thickness of ice, in feet, that the vessel can break without having to stop and ram. The regulations accompanying the Act specify the ice pressure to be expected at the bow, various intermediate hull sections and at the stern of the vessel (Appendix III). This pressure information provides the basis for the structural requirements defined in the same regulations. However, experimental and full scale data on ship-ice impacts suggests there is little correlation between the distribution of maximum pressure, actual load, and the velocity of the ship (9). In fact, there are strong indications that the maximum pressure experienced over a small area of the hull is predominantly a function of the properties of the ice involved in the collision rather than the ship motion at the moment of impact. This implies that proceeding slowly in the presence of ice will not necessarily reduce the force of a ship-ice impact.

In terms of ice hazard detection, it is clear that the lower "class" of the vessel, the more important it is to avoid contact with the harder, multi-year or glacial ice. General hazard detection standards are layed down in the Navigating Appliance Regulations of the Canadian Shipping Act. Schedule D of these regulations requires that a ship's radar be capable of clearly displaying under normal propagating conditions, an object having a reflecting area of 10 m^2 at ranges between approximately 100 m and 4,000 m. (The relevant sections of these regulations are quoted in full in Appendix III). In terms of glacial ice, such a target might correspond to a growler 10m^3 with a freeboard of approximately 1 m, weighting approximately 1,000 tonnes. Such a small piece of ice is likely to be moving with the waves and, having rolled many times, to be well rounded. Experience, particularly aboard the drill ships off Labrador with an ice observer on duty at all times, indicates such a target would be almost impossible to detect with conventional marine radars because of its lack of clear cut reflecting surface. Also, if the waves are significantly more than 1 m in height, the lack of continuous line of sight between the radar antenna and the ice further aggrevates the problem of detection. This situation does not improve close to the vessel, as the return from the ice can be lost in a sea clutter under such conditions.

3.2 Grand Banks Drilling Operations

On the Grand Banks south and east of Newfoundland, pack ice extends into the drilling area every 5-10 years, and is generally melting rapidly. Icebergs are also breaking up and melting rapidly. In fact, sea ice and icebergs are sufficiently rare to permit operators to use anchored semi-submersible platforms which are the least affected by inclement weather. However, because of the lack of mobility and the long lead time required to disconnect the anchors in an orderly manner, the alert zones are very much larger than off Labrador. The operational routine calls for ice to be detected as soon as it comes within 200 km of the drilling location. When it comes within 80 km of the site, a supply boat is usually sent to tow or stand by the iceberg until it is outside the 80 km zone.

Disconnect procedures, both drilling and anchors, are initiated when the iceberg comes within 40 km. Not all the anchors are let go immediately. For instance, when an iceberg came witin 10 km of a rig during January, 1983, the rig had let go all but two anchors before the ice drifted away again.

Thus, for anchored drilling platforms, the objective is to detect ice and begin tracking before the target come within range of any line-of-site detection system aboard the rig. Up to now, detection has been by visual aircraft reconnaissance and occasionally by special supply boats sorties. Side looking airborne radar (SLAR) is being considered for the reconnaissance task out to 200 km from the rig during 1983. Both the drilling platform and the supply boats carry conventional marine radars working at X-band, occasionally backed up by S-band. One drilling vessel has rcently installed an automatic radar plotting aid (ARPA) capable of tracking several targets automatically. However, the system was designed for detection and tracking of conventional radar targets and it remains to be seen how effective this system is in tracking sporadically visible targets, such as small pieces of glacial ice.

3.3 Labrador Sea Drilling Operations

Drilling operations off the coast of Labrador start early in July, when the pack ice has cleared the well sites, and continues to late October when severe sea conditions make continued drill ship operations uneconomic. All the sites are in the path of icebergs moving south with the Labrador current, so dynamically positioned drill ships, actually used because of the deep water, are the preferred platforms, with occasional use of dynamically positioned semi-submersibles. The operating companies have developed routine iceberg avoidance procedures, and no serious accidents involving ice and drilling platforms have been reported. Conventional X-band and S-band marine radars mounted above the bridge on the drilling vessels are the primary ice sensors. The nominal range is 50 km which, more realistically, is 30 km (COGLA regulations require 40 km minimum range capability). The radii of the various alert zones are dependent on

the speed of the iceberg and the number of hours required to terminate operations (Table 1.) The disconnect zone is fixed, with a 1 km radius.

NORDCO Limited's observers aboard these vessels report varying success in detection, tracking, and prediction of the drift paths for the icebergs. Detection range is a function of the size and shape of the iceberg, oceanographic and atmospheric conditions, which can change from one hour to the next. Deflection of the icebergs away from the drill ship by towing, although difficult in the case of small, rounded icebergs, is routinely attempted under the control of the ice observer aboard the drilling vessel. A further operational difficulty encountered under adverse weather conditions or darkness is the loss of contact with small pieces of glacial ice, such as growlers, in the radar clutter as they come close to the ship.

TABLE 1
LABRADOR

1) Detection: nominal 50 km
realistic 30 km
COGLA radar range (min. 40 km)

2) Disconnect zone: 1 km

3) Red Zone: inner edge = 1 km
outer edge = greater of 1 or 2
a) 1 km + 2 x hourly speed of fastest berg
b) 1 km + (number of hours to secure well) x hourly speed of fastest berg.

4) Yellow Zone: inner edge = outer edge of Red zone
outer edge = greater of 1 or 2
a) outer edge of Red zone + 4 x hourly speed of fastest berg
b) outer edge of Red zone + (number of hours to terminate operations) x hourly speed of fastest berg.

5) Green Zone: inner edge = outer edge of Yellow zone
outer edge = limit of radar range.

3.4 Beaufort Sea Drilling Operations

Operations in the Beaufort Sea range from year round drilling from artificial islands and caisson structures resting on berms, to anchored drill ships. In all cases specialized vessels are required to support drilling operations: dredges for the islands, icebreaking supply boats, barges, etc. Ice conditions range from open water with occasional ice floes during the brief summer, to 2 m of the fast ice nearshore with Arctic pack ice gradually moving east to west beyond the shear zone during the winter months. Within the pack, multi-year floes, the occasional ice island and consolidated ridges and other areas of normally thick ice constitute the main impediments to year round operations. Artificial islands are restricted to relatively shallow water, and one of the objectives during the exploratory phase of drilling is to extend deep water drilling using floating platforms into the winter months. During the summer, the requirement is to detect individual floes around the drilling vessel in time for supply boats to break them up or divert them. During the winter months the requirement is more complex. The movement of the pack ice becomes important and there is a need to distinguish multi-year from first year floes, and heavily ridged and rafted first year ice from smooth first year ice. The problem such features pose to present operation techniques is ice ride up onto the artificial islands, or movement of the caissons under pressure from the moving pack ice. The prevention of pressure from heavy ice will remain the priority problem as the use of deep water floating systems is extended more and more into the dark winter months.

Radar is the key ice hazard detection device in Beaufort Sea operations. Tactical support is now provided by operational side looking airborne radars (SLAR), or more experimental synthetic apperture airborne radars (SAR), with standard marine radars providing the close tactical information required by supply boats moving between shore bases and drilling vessels themselves. For the past two years experiments have been carried out with the radar antennas on artificial islands and aboard the drilling vessels being mounted as high as possible, generally on top of the drilling tower, and with

digital colour displays instead of the standard PPI. The major research effort has been directed toward tracking of pack ice movement during the winter months.

3.5 Current Requirements and Priorities

Table 2 summarizes the nature of present day and anticipated future requirements for ice hazard detection/avoidance capabilities. In this section, each geographic area is addressed in turn.

The movement of gas from the Arctic Islands and the Beaufort Sea is not expected to start before the late 1980's, and oil not before 1990. Thus, apart from local ship movements within the Beaufort Sea, no shipping is expected to be passing through the Northwest Passage year round for at least four years. When this does occur, a sophisticated ice system with automatic detection and collision avoidance capability will be required. It is still open to question whether it will be necessary to use sensors such as sonar, infra-red and low light level television (LLTV) to back up the conventional radars (which may be S-, X- or K- band). It is possible that ice detection/avoidance capabilities might be related to the ice capability of a vessel as defined in the Arctic Waters Pollution Prevention Act, and its accompanying regulations that restrict the movement of different classes of vessel to different areas throughout the year.

Ice, generally in the form of icebergs, bergy bits, and growlers rather than pack ice, has always been a hazard to navigation on the Grand Banks, particularly during the spring when fog is also common. The International Ice Patrol operated by the United States Coast Guard carries out ice reconnaissance flights during this period, but the information provided is rarely specific and often based on iceberg sightings several days old. Despite this, not a single accident has occurred outside the promulgated limits when mariners have received the ice bulletin. However, incidents still occur in areas of particularly numerous icebergs, such as the northern entrance to the Strait of Belle isle. This situation has recently changed with the

TABLE 2

Approximate Timetable for Operational Ice Hazard Detection/Avoidance Systems

Region	Operation	Date Required	Capability Required*
Northwest Passage	- Year round icebreaking LNG carrier moving east through Baffin Bay (2 vessel pilot project?)	1986-7	- Ability to detect glacial and multi-year ice (greater than 10^3 tonnes) in all sea states and when embedded in first year ice, minimum detection range 5 km. - Ability to distinguish between first year ice leads, and ridges or other areas of abnormally thick ice, minimum range 5 km.
Grand Banks of Newfoundland	- Exploratory drilling	immediate	- Ability to detect, track and predict movement of major icebergs within 200 km of site.
	- Supply vessels	immediate	- Ability to detect and avoid all glacial and sea ice in vicinity of vessels and drilling platforms, minimum range 5 km.
	- Semi-submersible production platform - Gravity based production platform - Tanker moving oil to shore	1986-7	- Ability to detect, track and predict movement of all ice (greater than 10^3 tonnes) between 46° & 48°N, 47°W and the Newfoundland coast.
Labrador Continental Shelf	- Exploratory drilling (open water period)	immediate	- Ability to detect, track & predict movement of major icebergs within 50 km of site, and all ice within 5 km
	- supply vessels		- Ability to detect and avoid all glacial and sea ice in vicinity of vessel, minimum range 5 km.
	- Oil or Gas production	1990	- Similar to Grand Banks requirement with emphasis on area up to 200 km north of production site.
Beaufort Sea	- Exploratory drilling	immediate	- Ability to detect, track and predict movement at multi-year and abnormally thick first year ice within 20 km of site.
	- Supply vessels		- Ability to detect and avoid all ice masses greater than 10^3 tonnes, minimum range 5 km.

TABLE 2 (Cont'd)

Region	Operation	Date Required	Capability Required*
	- Oil or gas production and shipment west around Alaska (2 vessel pilot project?)	1988-90	- Ability to detect and avoid as far as possible, all multi-year and abnormally thick first year ice, minimum detection range 5 km.

* Detection capabilities must apply during periods of darkness, and severe atmospheric conditions (fog, rain & snow) and oceanographic conditions (e.g. 10 m waves are relatively common on the northern Grand Banks).

year-round drilling in the area of the Hibernia oil discovery approximately 400 km southeast of St. John's. The three, relatively immobile, anchored, semi-submersible drilling vessels are potentially vulnerable to ice damage, and the operating company, Mobil, uses aircraft and ships to maintain a close watch on all ice within 200 km of the drill rigs. By the mid 1980's there may be many more drilling vessels, plus production platforms (either floating or resting on the seabed), pipelines (from well heads to productions facilities and, possibly, to shore), numerous supply vessels and possibly several oil tankers moving oil from offshore loading points to shore.

Mobil has recently requested proposals for an Ice Detection System tailored to their requirements in the Hibernia area. This may result in an ice management zone similar to that in the Beaufort Sea, extending eastwards from the coast of Newfoundland to encompass all areas of activity in the vicinity of Hibernia. If this should be the case, the ice detection will be accomplished using a combination of radar equipped aircraft and surface vessels. However, HF radar is being developed on the east coast and, depending on the results of research being carried out over the next year, may provide an alternative to airborne surveillance, or at least help maintain 40-100 km range detection capability from the drilling or production platforms between aircraft sorties.

The most pressing problem, both on the Grand Banks and off Labrador, is the detection, tracking and drift prediction of small pieces of glacial ice on a continuing basis. Even under ideal conditions these generally well rounded pieces of ice are difficult to detect using radar, and virtually impossible to detect in bad weather and in the radar clutter zone close the vessel when knowledge of their whereabouts is vital to the safety of the operation. At present, exploratory drilling and commercial shipping off Labrador is restricted by the presence of pack ice during the winter, so the problem is essentially that of detecting small pieces of ice during the open water season. Any research on this problem will have general application to Arctic shipping, operations in the Beaufort Sea, as well as those on the Grand Banks and off Labrador.

Oil companies in the Beaufort Sea, by a combination of airborne radar reconnaissance and ice reports from ships, coupled with a forecast model, are able to continue operation under all ice conditions within the ice capability of their different vessels. Ice detection, as such, is not a limiting factor in these operations. However, there is a need to distinguish areas of multi-year ice within the first year ice cover, and to gain a better understanding of the dynamics and development of rubble fields which develop around the artificial islands and caisson systems. This concern can lead to the improvement in all weather ice detection systems that might have application to conventional shipping. For instance, improved displays and the ability to downlink and display SLAR imagery have already been demonstrated.

4.0 CURRENT R & D PROGRAMS

4.1 Review of Information from Questionnaire

Questionnaires seeking information on current R & D projects in ice detection using land or sea based instrumentation were sent to fourteen organizations. Twelve groups responded and thirteen projects were identified. In some cases the completed questionnaires were submitted by groups affiliated to those to whom the questionnaire was addressed, and in some cases projects were reported more than once by different participants. The questionnaires are reproduced in Appendix I. In summary, one project was concerned with the laboratory study of the characteristic response of sea ice at microwave frequencies, two with basic research into the sensitivity of various radar parameters to sea ice features, two with radar signal enhancement and display techniques, two on the development of integrated multi-sensor ice detection systems, and three with high frequency (HF) radar techniques. Finally, three projects were primarily concerned with the application of ice sensing techniques. Much of the recent research is described in Appendix I, and comments in this section will be confined to a few generalities.

The laboratory study of the electrical properties of ice being carried out by the Bayfield Laboratory of the Department of Fisheries and Oceans in co-operation with the University of Toronto is intended to improve on understanding of the dielectric properties of ice in the 250-800 MHz range. This falls between that of HF radar at 20-30 MHz and the lowest conventional marine radar at 2-4 GHz (S-Band). The experiment has been designed primarily as an aid to understanding the performance of ice thickness measuring radars. However, the experimental techniques may have application at both the higher frequencies used in conventional marine radars, and at the lower frequencies where there is considerable interest in the performance of HF radars. A complimentary study by the Snow and Ice Division of the National Hydrology Research Institute of Environment Canada, examines the information available on the response of ice to excitation at radio frequencies, ranging through the microwave region to infrared, visible and ultraviolet frequencies (1).

McMaster University and the Bayfield Laboratory of the Department of Fisheries and Oceans, using the Borden Penninsula camp overlooking Lancaster Sound, have a program aimed at determining the optimum parameters for an ice navigation radar. Ice conditions at the site range from fast ice and slowly moving pack with all the commonly encountered first year ice feature during the winter, to open water with occasional flows and icebergs of various sizes during the summer. Experiments up to now have used conventional marine radars operating in the X-band (8-12.5 GHz) and the S-Band (2-4 GHz). Future work will include K_u (12.5 - 18 GHz) and K_a (26.5 - 40 GHz), and coherent X-band radar evaluation. Although atmospheric attenuation of radar signals increases with increasing frequency, the Arctic atmosphere is 'dry' much of the time and K-band radars may be useful for short range, detailed detection and mapping of ice features.

Other radar parameters being investigated by these two groups are the effects of power, antenna gain, beam width and polarization, scanning rates, pulse length and repetition frequency. One of the problems that has been identified in the detection of small pieces of ice at the low grazing angles typical of marine radars is the loss of return when signals travelling along different paths interfere. This is now being investigated by the groups operating from Borden Penninsula. Future plans include the construction of an X-band research radar and, possibly, a K-band radar.

Two companies have developed enchanced display systems - one digital and the other analogue. Both use TV format and can show amplitude of the return signal in colour or grey level (provided the radar has been calibrated), and have the capability for scan-to-scan averaging if required. Both represent a considerable improvement over the conventional PPI. The C-CORE analogue display system, now the technique has been shown to be feasible, is regarded as complete for the time being. The Intera Environmental Consultants Ltd. radar image display system (RIDS) has gained general acceptance with Beaufort Sea operators for the display and recording of pack ice imagery. On the east coast, the conventional automatic radar plotting aid (ARPA) has been included onboard one of the rigs on the Grand Banks, but no

information is available regarding the effectiveness of this equipment for ice detection and tracking. The more flexible RIDS and C-CORE systems, which can be used either operationally or in a research mode, have not been evaluated for iceberg detection.

One company, Remotec Applications Inc., has reported a capability to provide an integrated computer supported multi-sensor data enhancement and display system and a second company, Viatec Resource Systems Ltd. is in the midst of a multi-sensor system definition. Although some operators have expressed an interest in integrated, multi-sensor systems, most seem to prefer to pursue single sensor evaluation programs for the present. The merits of integrated, multi-sensor system development at this stage are discussed later, in Section 4.2.

Four projects working in the HF 10-30 MHz range have been reported. One is a theoretical analysis of groundwave propogation over seawater and sea ice or glacial ice by the Faculty of Applied Sciences and Engineers at Memorial University of Newfoundland. The second, carried out C-CORE, involves the transfer and demonstration of the National Ocean and Atmospheric Administration (NOAA) coastal ocean dynamics applications radar (CODAR) developed for surface current mapping. The technnique will then be evaluated when sea ice or icebergs pass within range of the transmitters which cover an area of approximately 50 km^2.

The third project, also by C-CORE involves more basic experimental research in HF propogation over the sea surface and the verification of theoretical predictions of sea ice and glacial ice effects within the beam path (2,3,4). The fourth project by Battelle Columbus Laboratories has been reported by an oil company. The system is based on multi-static HF radars based on ships, buoys or drilling platforms, and is designed to detect ice up to 150 km away. System specifications have been completed and prototype hardware designs are currently being developed. This project has the support of Canterra Energy Ltd., Mobil R&D Corporation and Petro Canada. In contrast to microwave radars, which are essentially line-of-sight (and even this

may be reduced by prevailing atmospheric conditions), HF groundwaves can be used to detect targets beyond the visual horizon. Assuming HF radar can be shown to be useful for ice detection, significant development work is still required for operational antenna systems, and signal processing techniques.

Aside from the Canterra report on the Battelle program, Gulf Canada Resources Inc., have reported on their experience in the detection, monitoring and forecasting of various ice conditions in the Beaufort Sea - much of the work being carried out in co-operation with Dome Petroleum Ltd. The system incorporates side looking airborne radar or synthetic aperature radar imagery, data from supply vessel and drillship radars (some with enhanced displays using RIDS). Gulf has expressed a continuing interest in the development of remote sensing for the assessment of ridge cross-sections and their degree of consolidation, as well as for the detection of small pieces of multi-year ice in a matrix of first year material.

Esso Resources Canada Ltd. report no active research program. However, in the Beaufort Sea the company is using marine radar (possibly with enhanced display) to monitor early season ice conditions around the artifical islands with a view to improve their knowledge of the dynamics of rubble fields.

4.2 Evaluation of On-going R&D

Based on the completed questionnaire and discussions with researchers active in the field of ice detection, it is possible to draw several conclusions. However, it must be recognized that the information base may not be complete and, consequently, the conclusions may be erroneous in some areas.

(i) Conventional marine radar operating in the X and S bands, is seen to be the key element in any ice detection system onboard a vessel or drilling platform. Most of the R&D effort to date has been to optimize the choice of parameters for essentially off-the-shelf radars, with the option of a

video display replacing the conventional PPI. The video display systems do provide the opportunity to apply various signal enhancement procedures.

(ii) There is a significant level of microwave radar (X, S and K band) R&D being carried out in Canada. The key groups are at the Bayfield Laboratory in the Department of Fisheries and Oceans and at McMaster University. These groups are co-operating between themselves and with the Radar Research Group at the Department of Communications. The university, at least, has secure funding for the next two years and can build X- and K- band research radars specifically designed for ice detection. The Borden Penninsula site used by these groups has all year access and overlooks the full range of first year ice types during any given year. Glacial ice targets are common, but may not come within reasonable range of the station in a given period. Multi-year ice targets may be the least common but, again, depending on the year. To date, the basic research carried out by the groups has, probably correctly, not been tied to the fulfillment of any particular set of operational requirements.

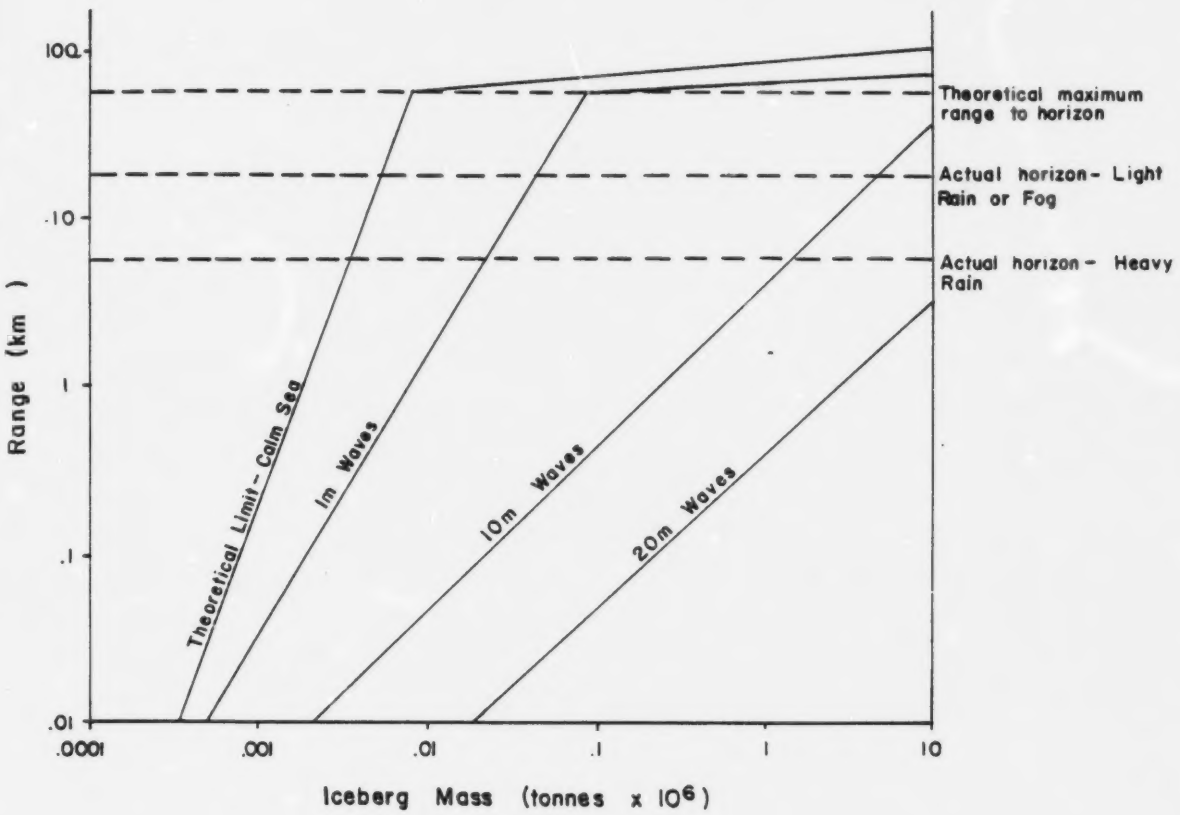
iii) For certain applications, the capability to detect large ice masses beyond the visible horizon is important, and the HF radar development may make an important contribution in this area.

iv) Very little research is currently being undertaken to evaluate and develop acoustic, visible and infrared sensing systems that might have great value for short-range (less than 5 km) detection of ice. Until they have been evaluated individually, it is difficult to justify their inclusion in any multi-sensor system.

v) One of the key outstanding deficiencies is a means of assessing the effectiveness of any particular ice detection device, whether it be a radar, sonar, visible or infrared system. The author believes a statistical analysis is required based on data sets of similar quality. For example, glacial ice observations in the Labrador Sea, and pack ice information from the Beaufort Sea. The framework for such an analysis might be similar to that illustrated in Figure 1, where each diagonal line represents the 95% confidence limit for detection of targets falling below and to the right of the curve. This approach permits the qualitative inclusion of sensor range under varying oceanographic and atmospheric conditions.

vi) Although it is technologically possible to develop an integrated, computer controlled, multi-sensor ice hazard detection/avoidance system, there is insufficient experience with the individual sensors to justify such an investment for the time being.

vii) No single R & D group in government, industry or accademia has the combination of experience in operational requirements in the presence of ice, plus an electronics and computer background, and familiarity with the logistics of field tests under offshore sub-arctic conditions, to undertake a successful sensor evaluation.



ICE HAZARD DETECTION
SENSOR PERFORMANCE CHART

FIGURE 1

5.0 TRANSPORTATION DEVELOPMENT CENTRE (TDC) INVOLVEMENT

5.1 Past and Present TDC Activities

To quote from the 1980-81 TDC annual report (TP 3230), "Ships operating in ice infested waters rely basically on watch observers to detect ice hazards. Visual sightings are ineffective at night and in poor weather conditions, requiring ships to proceed very slowly. Furthermore, despite the precautions taken in ice infested waters, accidents are alarmingly common. An effective method for detection and avoiding ice hazards under all environmental conditions is vital to the safe and efficient transport of oil and gas resources from Northern Canada".

During 1978-79, Arctec Ltd. conducted a comprehensive assessment of the technologies required for year round Arctic marine operations. The report reviewed the then current state of technology in the various sub-systems that make up a large icebreaking commercial vessel, including hazard detection/collision avoidance systems, and provided a framework for future R & D (5,6). At the same time, ICE Engineering Ltd. completed a study of iceberg detection methods and their reliability. This company concluded that year round navigation in the Arctic and off the east coast would be unsafe, given the then current level of iceberg detection technology (7). In 1980 MPB Technologies Inc. completed the development of a vortex-stabilized arc source for marine applications (8). This prototype, high intensity light source for masthead installation was developed to meet Canadian Coast Guard requirements.

With this background, TDC, with Petro-Canada, undertook a major project to evaluate the effectiveness of a variety of ship-mounted sensors for ice detection. The M.V. "Polarhav" was equipped with X- and S-band radars, sonar and infra-red sensors. From July to October 1980, the ship travelled up the Eastern Arctic coast to North Baffin Bay and Lancaster Sound to collect correlated field data using

different operational modes. The data is now being analyzed and will be a major asset in the development of future ice hazard detection systems, based on a composite array of sensors and displays.

5.2 Recommendations for TDC Involvement

Table 2 summarizes the requirements for detection of hazardous ice conditions in suport of operations around the coast of Canada. Some requirements are immediate, and these are being met using essentially off-the-shelf equipment. Other requirements have significant lead-times, but it must be born in mind that sophisticated sensors can take up to three years to develop. Therefore, the following recommendations for continued and new research should be pursued on an urgent basis.

Current ice detection R & D is fragmented between a number of groups and some of the work is confidential. The next two recommendations address this problem:

(1) A workshop on ice detection should be organized within 12 months to review the full spectrum of operational requirements, programs underway and progress to date. Possibly, McMaster University should be asked to organize such an event.

(2) Close links should be established and maintained between operators and R & D groups - particularly as most operations can accommodate R & D work on a non-interference basis, with consequent savings.

The following recommendations relate to technology development:

(3) Development of an integrated, computer-controlled, multi-sensor ice detection/avoidance system should not be undertaken by TDC because the performance of such a system will have to be tailored to the specific operating requirements of the ultimate user. TDC should concentrate on the assessment of the potential components of such a system.

(4) The utilization of airborne SAR/SLAR imaging radar information in conjunction with shipboard radar requires investigation, both in application and in display/analysis techniques. Transmission of SLAR imagery from an aircraft to a ship for display has been achieved, but the use of such information as an aid to interpreting marine radar data requires further study.

(5) A program of radar clutter analysis should be initiated to establish the detectability of small pieces of ice close to a vessel or drilling platform. The results of such a study will contribute to establishing the requirements for sensors, other than microwave, for short range detection.

(6) A program of underwater acoustics should be established to address the theoretical aspects of the ice detection problem using horizontal, near-surface sonar. This analysis should be carried out in conjunction with laboratory tank tests, and prior to field tests.

(7) HF radar research, with its potential for over-the-horizon ice detection, should be continued with emphasis in the near future on carefully controlled field experiments.

(8) The X, S and K band radar experiments at Cape Borden should be continued with the additional task of investigating the improvement of real-time data analysis and information display techniques.

Although not part of TDC's mandate, two regulatory changes need to be considered:

(9) The inclusion of a better definition of ice detection requirements, possibly as a function of ice class of the vessel or drilling platform, in the updated Canadian Arctic Shipping Pollution Prevention Regulations.

(10) The possibility of Canadian Oil and Gas Lands Administration guidelines recognizing differences between Beaufort Sea (anchored drill ship and artificial island), Labrador Sea (dynamically positioned drilling vessels), and Grand Banks (anchored drilling vessels) ice detection requirements as a function of platforms and the drilling task in hand.

REFERENCES

Environment Canada:

1. G.P. Johari, 1981. The spectrum of ice. Contemp. Phys. 22, pp. 613-642.

Memorial University of Newfoundland:

2. J. Ryan and J. Walsh, 1983 (in preparation). Electromagnetic scattering from a vertical discontinuity with application to ice hazard detection.

3. S.K. Srivastava and J. Walsh, 1983 (in preparation). An alternate analysis of HF scattering from an ocean surface.

4. J. Walsh, 1982. A general theory of the interaction of electromagnetic waves with isotropic, horizontally legend media, and applications to propogation over sea ice. C-CORE report 82-9.

Transport Canada:

5. Arctec Canada Ltd., 1978. Development of a research program for improving Arctic marine technology. Three volumes, TP 2003, 2004, 2005.

6. Arctec Canada Ltd. 1979. Summary report of above, TP 2006.

7. C.P. Benedict and J.C.E. Hall (Ice Engineering), 1979. A study of iceberg detection for marine navigation. Final report TP 2409. C.P. Benedict and J.C. Hall, 1980. Summary report of above, TP 2414.

8. MPB Technologies Inc., 1980. Development of a vortex stabilized are source for marine applications. TP 2662.

9. Arctec Canada Ltd., 1982. Studies supporting update of the CASPP regulations Group I and II, Final Report. Ship Safety Branch, Canadian Coast Guard, Transport Canada.

Other references appear in Appendix I on the individual project reports.

Appendix I
Description of Current R & D Projects

NORDCO - TDC QUESTIONNAIRE

ON ICE HAZARDS DETECTION DEVELOPMENT

GULF CANADA RESPONSE - F.J. ELEY - JANUARY 27, 1983

TITLE: Development of real-time support to ice-sensitive drilling systems for year-round Beaufort Sea drilling and production.

Keywords: ice detection, communication, ice models, ridges, multi-year.

Organization: Frontier Development Ocean Engineering Research Group, Gulf Canada Resources Inc., P.O. Box 130, Calgary, Alberta, T2P 2H7.

Contact: B.D. Wright, F.J. Eley

Telephone: (403) 233-3896/4352

Project Team: F.J. Eley, operating staff, contractors

Summary: Aim: To provide ice monitoring and forecasting ability to drilling vessels whose operation is sensitive to various sizes of ice ridges or masses/thicknesses of multi-year ice floes. Hazardous ice must be detected and predicted long enough in advance to permit orderly shut-down of drilling and securing of the well. The economic benefit comes from maximizing prudent drilling right to the time when a dangerous ice feature arrives.

Method: The initial phase has been a survey of the state of the art and implementation of that technology in support of a drilling system beginning with the 1983 season. Operation of the system will be self-documenting and additional ground truthing will be done on-ice and with high-resolution aerial photography. New technology will continue to be tested as opportunities arise.

Progress: (i) Gulf has acquired experience in the use of SLAR, SAR, aerial photography, marine radar, impulse radar, acoustic thickness measurement and marine radar display enhancement prior to going operational.
(ii) We are presently setting up an operational support system, largely in cooperation with Dome Petroleum, which will utilize SLAR, SAR, marine radar, ice drift models and radar display enhancement.

(iii) In future, we will continue to test promising technology to solve outstanding problems which include full assessment of ridge cross-section and consolidation by remote sensing, and detection of rather small pieces of multi-year ice in various types of ice background.

Facilities: Operational ice data management system and some funding to continue development programs.

Available Publications: Spedding, L. C., B. Mercer and D. L. Schwab, 1982. Sursat Beaufort Sea Experiment No. 41 -- SAR, SLAR and aerial photography cross-section correlation. Surveillance Satellite Project Office, Ottawa.

Mainly in-house reports.

Timescale: Will continue. Gulf interested in producing oil in Beaufort, Arctic Islands and Hibernia by early 1990's. Present system operational for 1983 summer season.

Fulltime Staff: 2, plus seasonal operators and project contractors.

Confidentiality: Mostly confidential except projects jointly with public institutions.

FJE/tls

Title: Evaluation and development of a computer-controlled surface-based ice hazard detection system.

Keywords: radar, IR, sonar, LLLTV, detection, enhancement, icebergs, sea ice floes, ice hazard, multi-sensor.

Organization: REMOTEC Applications Inc.

Address: P.O. Box 5547, St. John's, Nfld., A1C 5W4.

Contact: Mr. Richard D. Worsfold (President), Dr. Surendra K. Parashar (Vice President), or Mr. Byron R. Dawe (General Manager).

Telephone: (709) - 364-1779

Collaborating Organization:

Project Team: S. Parashar, B. Dawe, R. Worsfold, J. Husa, K. Mews, R. Wood, D. Millan, and others, including students.

Summary: Aim: To develop a computer-controlled surface-based (ship or drilling platform) ice hazard (icebergs and sea ice floes) detection system comprising of radar, IR, sonar, and LLLTV sensors. The system to include multi-sensor-integration or data fusion through a central computer unit and display device, clutter reduction or target enhancement, and automatic target detection capability. Also to maintain ongoing assessment of new and other sensor systems.

Method: i) A 90 day field trial conducted in Baffin Bay during 1980 for acquisition of large amount of radar video and IR data. Radar data obtained with a specially configured multi-parameter system. This project included theoretical evaluation, market survey, and preliminary data analysis. Work conducted as a sub-contract to Petro-Canada Exploration Ltd. under a DSS contract sponsored by TDC.
ii) System specifications and design based on theoretical evaluation, data analysis, and computer modeling and simulation. In-house work with support from NRC.

Progress: i) Evaluation of full-bandwidth analogue recordings of radar video data corresponding to x and s frequencies, HH and circular polarizations, different antenna heights, different antenna beamwidths, different antenna rotation speeds, and different pulse lengths.
ii) Quantitative evaluations of radar returns on A-Scope and of some digital radar video data including computation of radar cross-section and signal to noise ratios for various ice hazards.

iii) Pulse to pulse and scan to scan averaging for clutter reduction or target enhancement evaluation.
iv)Correlations among different data sets.
v) Evaluations of analogue and digital IR images corresponding to different parameters.
vi) Image enhancement techniques applied to digital IR images.
vii) Preliminary system specifications have been developed.
viii) Simulations of multi-sensor signal presentation display.
ix) Future Program: complete system design using computer simulation and modelling.

Facilities: HP-1000 (128 Kbyte Core)
120 Mbyte disc drive
1600 bpi tape unit
Norpak Video display processor (SYS-2),
10 bit planes, 640 x 480 x 8 bit color display

Associated Publications: "Evaluation and Development of an Integrated Ship-borne Ice Hazard Detection System - Phase I, Vol. 1 to 6, - Theoretical Evaluations"
"Evaluation and Development of an Integrated Ship-borne Ice Hazard Detection System - Phase II, Vol 7, Technical Plan for Field Evaluation"
"Evaluation and Development of an Integrated Ship-borne Ice Hazard Detection System - Phase II - Field Evaluations".
These reports were prepared for Petro-Canada and are believed to be confidential.

Timescale: Started January 1979, continuing at least to 1985 when a proto-type system will be ready after field testing.

Full Time Staff: 4, plus students

Budget: First part from 1979 to 1981 funded by Petro Canada and TDC under the DSS contract; budget cost for the project in excess of $3 M total. Funding during 1981 and 1982 under NRC IRAP; about $200,000 per year. Future funding through private investment capital.

Confidentiality: Unrestricted when government funded, negotiable when private industry involved. The field program and associated work was confidential due to involvement of Petro-Canada and other companies.

Sponsors: TDC, Petro-Canada in consoritum of other companies, NRC (IRAP), Private

Viatec IHD/CAS Current Work

TITLE: Specification Investigation and Data Assessment: Ice Hazard Detection/Collision Avoidance System

KEYWORDS: Remote sensing, surface systems, ice, detection, classification, analysis

ORGANIZATION: Viatec Resource Systems Inc., Penthouse Suite, 736-8th Ave. S.W., Calgary, Alberta T2P 1H4

CONTACT: Michael Harvey

TELEPHONE: (403) 269-4240

COLLABORATING ORGANIZATION: TDC

PROJECT TEAM: Michael Harvey, Andrew Gotizewskie, Bryan Dawe plus others

SUMMARY:

Aim: To develop a ship mounted ice hazard detection/collison avoidance system for more efficient and safe marine transportation and operations; specifically to refine the system specification for an ice hazard detection and collision avoidance system, to investigate all the options available, and to make a preliminary assessment of the sea trials data currently available.

Method: Fully discuss with all likely organizations the various aspects of the preliminary system specification for the ice Hazard Detection/Collision Avoidance System and clearly determine the various concerns and requirements of each organization. Establish a definite development time scale in relation to the different offshore/arctic requirements. Determine and define where development is needed, including likely Canadian participants to the development effort. Finalize system specification. Formulate an initial evaluation plan, work out necessary arrangements and perform a preliminary assessment of the PEX/TDC phase 2 sea trials conducted by Remotec.

Progress: Preliminary system specification is curretly being completed. Discussions are ongoing with potential user requirements, and supplier capabilities and programs. All arrangements to perform data assessment have been completed.

FACILITIES:

Decca Marine Radar Display
A-scope adaptor
Radar Recording System RR100 including
(a) recorder
(b) interface unit
(c) power invertor

Tectronix 466 Oscilloscope
Sangamo Sabre IX Moder 4922 Recorder
Sony AV-3400 Video Tape Recorder

TIMESCALE: Started January, 1983 continuing for six months

FULL-TIME STAFF: 2

BUDGET: $64,000 total

CONFIDENTIALITY: Unrestricted

SPONSORS: TDC

TITLE:	Research on High Frequency (HF) radar for detection of sea ice
KEYWORDS:	Sea ice hazards, HF radars
ORGANIZATION:	Faculty of Engineerin and Applied Science, MUN, St. John's A1B 3X5
CONTACT:	John Walsh
TELEPHONE:	(709) 737-8963
PROJECT TEAM:	J. Walsh, B. P. Sinha (MUN), W. Winsor (C-CORE), K. A. Butt (C-CORE), plus one research associate and graduate students.
SUMMARY:	Aim: To determine the feasibility of, and specifications for, an HF surface wave radar capable of detecting ice flows and icebergs. Method: (i) Development of an analaytical model representing HF transmission across a sea water - saline ice or glacial ice interface. (ii) Field experimetns to validate these models. Progress: A general formulation of the problem of detecting the electro-magnetic field resulting from a finite EM source placed above a horizontally layered isotropic medium has been developed. Initial analysis of field experimental data shows very good agreement between predicted and measured field strengths.
ASSOCIATED PUBLICATIONS:	Walsh, J. 1982. A general theory of the interaction of electo-magnetic waves with isotropic, horizontally layered media, and applications to propogation over sea ice. C-Core Technical Report 82-9.
TIMESCALE:	1982 to at least 1985.
FULL-TIME STAFF:	Four
BUDGET:	Approx. 85,000/year for three years
CONFIDENTIALITY:	Nil
SPONSORS:	NSERC, C-CORE & DFO

TITLE : Multi-Static Radar

KEYWORDS : As above

ORGANIZATION : Battelle Columbus Laboratories

ADDRESS : 505 King Avenue, Columbus, Ohio 43201

CONTACT : Ilene Zeldin
TELEPHONE : (614) 424-7728

COLLABORATING ORGANIZATIONS : Canterra Energy Ltd., Mobile R & D Corporation, Petro-Canada Exploration Ltd.

PROJECT TEAM : A. George Mourad and George T. Ruck

SUMMARY :

Aim: To develop an all-weather radar to detect and monitor ice conditions up to 150 km away.

Method: Use high frequency multi-static radars with transmitters on ships, buoys or coastal areas and receivers at users site; e.g. drilling rig or production platform.

Progress: System specifications and configurations already analyzed.
Currently developing prototype hardware designs for each component.

ASSOCIATED PUBLICATIONS :

TIMESCALE : Build and test prototype by December 1983.

FULL-TIME STAFF :

BUDGET :

CONFIDENTIALITY : Restricted to Battelle and sponsors.

SPONSORS : Canterra Energy Ltd., Mobile R & D Corporation, Petro-Canada Exploration Ltd.

TITLE: Saline ice electrical properties and radar measurement study

KEYWORDS: electrical properties, saline ice, radar

ORGANIZATION: Bayfield lab., Dept. of Fisheries & Oceans, Burlington, Ont. L7R 4A6

CONTACT: W. S. Haras

TELEPHONE: (416) 637-4338

PROJECT TEAM: W. S. Haras, E. O. Lewis, K. Iizuka (Univ. of Toronto), G. Tsang (DOE)

SUMMARY:

Aim: (i) To measure the electrical properties, namely the dialectric constant (complex) and the loss angle of saline ice.

(ii) To measure the thickness of saline ice with high frequency radar.

Method: Electrical properties of ice are a function of salinity, temperature, frequency of the applied voltage crystallographic form, orientation of the c-axis and electro-magnetic field. Laboratory experiments will be performed with fresh water ice of known properties, to be followed by experiments on saline ice (minus 4% sea, 35 o/oo salinity (uncontrolled), 250-800 MHz, 25-30 cm thick, with brine drainage periods included). All experiments to be in a laboratory tank. If successful subsequent tests will take place in the field.

Progress: Experimental procedures have been developed and the equipment acquired. Experiments complete for fresh water ice and on-going for sea ice.

ASSOCIATED PUBLICATIONS: Nil

TIMESCALE: 1982 to March 1983, with field tests in North West Passage during April 1983 if laboratory results satisfactory.

FULL-TIME STAFF: 2

BUDGET: 77K

CONFIDENTIALITY: Nil

SPONSORS: National Energy Program R&D, DFO

Title: Classification of sea ice types & features under winter conditions using surface based radar.

Keywords: radar, ice, classification

Organization: Dept. of Fisheries and Oceans, Ocean Science & Surveys, Bayfield Laboratory, P.O. Box 5050, Burlington, Ontario L7R 4A6

Contact: E. O. Lewis

Telephone: (416) 637-4356

Collaborating Organization(s): McMaster University, Georgia Tech., Dept. of Communication (Communication Research Centre), Arctic Research Establishment (Pond Inlet), Dome Petroleum and Intera Ltd.

Project Team: E. Lewis, T. Dyas

Summary:

Aim - To determine the backscatter characteristics of first and multi-year sea ice features under winter conditions using various surface based radars.

Method - Recordings have been made in the field of returns from different ice features using different radars. The experiments have been carried out at the DFO camp on Borden Peninsula overlooking Lancaster Sound and Navy Board Inlet.

Project - (i) Full bandwidth analogue recording of video from standard marine radars (Decca RM 1229 X-band, Decca RMS 1230 S-band, & Furono FRM 64W X-band) transmitting over fast ice for subsequent laboratory analysis of the effect of varying pulse length, polarization, height of antenna, beam width, X and S frequencies. Investigations included measurement of Lloyd's mirror effect over ice. Ground truth included on-ice party (from Arctic Research Est.) and aerial photography.

(ii) Repeat of above with digital recording during May 1983 using X, S, K_u and K_a band radars, plus (possibly) coherent

X and high power X band radars.
(iii) Future program (beyond 1983) uncertain.

Facilities

- Borden Camp, which has year round access by air (1200 x 100' airstrip and access to within 100' of camp), over ice (Dec. to June) and by sea (July to October) from Pond Inlet. On-ice parties and ground transportation, and camp maintenance provided by A.R.E. under contract to D.F.O. Buildings include an accomodation/ laboratory hut 20 x 24', ARE staff accomodation hut 12 x 16', plus generator shack and equipment storage facilities.

- Furono FRM 64W, X-band radar, plus other radars and recorders under contract as required.

- Luneberg lens radar targets.

- Alpine X-band radar transponders.

Available Publication

Ice radar experiment, Borden Peninsula, March 1981, E. Lewis Field Report Series 81-2.

Timescale: Started Nov. 1980, continuing at least to end of 1983.

Fulltime Staff: one

Budget: Approximately $250,000/year operating funds

Confidentiality: Unrestricted

Sponsors: NEP Energy R&D (DOT and DFO), DFO

Title: Investigation of surface-based radar parameters for ice detection and classification.

Keywords: radar, ice, detection, classification.

Organization: Communications Research Lab., McMaster University, Hamilton, Ontario, L8J 4L7.

Contact: Dr. Simon Haykin (Director)

Telephone: (416)525-9140 (4291)

Collaborating Organization: DFO (Burlington)

Project Team: S. Haykin, B. W. Currie, T. O. Greenlay, L. Bridle, plus students.

Summary: Aim: to develop a surface-based (ship, drilling platform or shore-based) radar specifically for monitoring ice conditions in close tactical support of operations. Method: Recordings have been made in the field of returns from different ice conditions using different radars. Most field experiments have utilized the DFO camp on Borden Penninsula overlooking Lancaster Sound & Navy Board Inlet. Progress: (i) full bandwidth analogue recording of video from standard marine radars transmitting over fast ice for subsequent laboratory analysis of the effect of varying pulse length, polarization, height of antenna, beam width, X and S frequencies. Investigations included measurement of Lloyd's mirror effect over ice. Ground truth included on-ice party and aerial photography. Project carried out under DFO contract. (ii) Repeat of above in May 1983 with digital recording (96 MB) of X and S in the field, and subsequently analysis of X, S, K_u and Ka (collected by Georgia Tech. under DFO contract). Also possibility of digital recording of coherent 'X' radar, and 100 KW 'X' non-coherent radar provided by Litton. (iii) Future program. Construction of instrument quality X and Ka coherent radars, possibly with phased array receiving antennas. Experiments will include fast ice and open water conditions from Borden site. Attempts will be made to improve the propogation equation for low-lying targets affected by multi-path phenomena (Lloyds mirror). Experiments will include target backscatter measurements.

Facilities: RCA Advisor analogue video recorder (2 channel, 6 MHz each).
Ampex HBR digital recorder (24 track, 4 MB each)
HP 1000 with Floating Point Systems AP 120B array processor
Intel 286 FD 8 bit/16 bit computer system with Matrox 512 x 512 x 4 bit colour display
Ramteck 9460 1280 x 1024 x 16 bit colour display with HP 1000.

../2

Available Publications:

- Application of radar to the detection & classification of sea ice. CRL report #86.
- Field report (March 1981) CRL #87.
- Processing & analysis of radar data collected March 1981, Borden Penninsula, NWT. CRL #106, in preparation.
- Effect of radar parameters on detection and classification of ice using surface based radar: I- radial line analysis; II-Colour coded display. In preparation for POAC, April 1983.

Timescale: Started Nov. 1979, continuing at least to 1986.

Fulltime Staff: 3, plus students

Budget: Operating $50,000/year from NSERC, plus DFO field support. NSERC equipment grant $294,000 for each of two years for X and Ka radars.

Confidentiality: Unrestricted when government funded, negotiable when private industry involved.

Sponsors: NSERC, NEP Energy R&D (via DOT, DFO), DFO, Dome Petroleum.

TITLE:	Interaction between HF electromagnetic waves & ice
KEYWORDS:	HF, radar, ice
ORGANIZATION:	Centre for Cold Ocean Resources Engineering, MUN, St. John's A1B 3X5
CONTACT:	K. A. Butt
TELEPHONE:	(709) 737-8370
PROJECT TEAM:	K. A. Butt and W. Winsor, C-CORE, J. Walsh, MUN
SUMMARY:	Aim: (i) To establish HF ground wave technology in Canada for oceanographic measurements. (ii) To investigate the application of HF ground wave techniques for sea ice and iceberg detection and drift prediction. Method: The first step was to investigate the use of HF sky wave transmissions for surface wind and wave measurements in cooperation with Department of Communications (Communications Research Centre). With this basic knowledge, transfer of NOAA CODAR Technology to C-CORE was started. HF ground wave techniques will be applied to the measurement of oceanographic phenomena and to this specific problem of ice detection. Progress: (i) The sky wave experiment is essentially complete and suggests the technique has potential, but the capital cost of an operational system is too high to consider at present. (ii) The CODAR technology transfer program will be complete with a demonstration scheduled to early 1983. (iii) Field tests for ice detection, using a special shore based, narrow beam antenna will begin in June 1983.
ASSOCIATED PUBLICATIONS:	
TIMESCALE:	1980-1985
FULL-TIME STAFF:	4
BUDGET:	Approx. $300,000 per year.
CONFIDENTIALITY:	Nil
SPONSORS:	National Energy Program, Energy R&D, DFO, C-CORE.

TITLE:	Radar Image Display System (RIDS)
KEYWORDS:	Radar, digital display
ORGANIZATION:	Intera Environmental Consultants Ltd., 4th Floor, 785 Carling Ave., Ottawa, Ont. K1S 5H4
CONTACT:	R. Lowry
TELEPHONE:	(613) 563-4343
PROJECT TEAM:	R. Lowry, R. Rhadakant, B. Raman
SUMMARY:	Aim: To optimize radar signal processing and display for detection, tracking and recording of sea ice features and iceberg targets. Method: Individual range strobes are digitized, averaged and stored for a varying number of scans on a disk for further processing. Data are displayed on a video monitor after conversion of range and bearing data to cartesian coordinates. Further processing can remove the effect of range and antenna gain variations. If the radar is calibrated, colours can be assigned to radar effectivities. Progress: Field experience now exists for operations in the Beaufort and Bearing Seas. Interfaces are available for Decca Raytheon and other common marine radars.
ASSOCIATED PUBLICATIONS:	To follow.
TIMESCALE:	Continuous development since 1980.
FULL-TIME STAFF:	Three
BUDGET:	Not available
CONFIDENTIALITY:	Hardware available for lease or purchase.
SPONSORS:	Intera Environmental Consultants Ltd., Dome Petroleum Ltd.

TITLE: Marine radar image enhancement

KEYWORDS: marine radar, image enhancement

ORGANIZATION: Centre for Cold Ocean Resources Engineering, MUN, St. John's, A1B 3X5

CONTACT: Ken Klein

TELEPHONE: (709) 737-8354

PROJECT TEAM: K. Klein and Ken Butt

SUMMARY: Aim: Improved radar display for ice features and ice conditions.

Method: A conventional marine radar PPI displays only those returns above a certain threshold strength. The C-CORE system, which has real time analogue storage, displays the strength of return as one of a series of discreet gray levels on a video monitor.

Progress: The system has been evaluated for a site near St. John's (Ship targets), and Cape Norman in Newfoundland and from Tarsiut drilling island in the Beaufort Sea under winter pack ice conditions. Practical antenna heights limit the useful range of the radar to about 11 km. The display system permits image-to-image averaging to improve signal-to-noise ratios, and store data permits time series analysis of image changes.

ASSOCIATED PUBLICATIONS:

TIMESCALE: 1981-1982

FULL-TIME STAFF: One

BUDGET: Low

CONFIDENTIALITY: Nil

SPONSORS: C-CORE, CN Marine, DOT/CCG

Addendum to Appendix I

TITLE: Shipborne Ice alert and Monitoring (SIAM) System

KEYWORDS: ice, forecasting, information presentation

ORGANIZATION: Dome Petroleum Limited, P.O. Box 200, Calgary, Alberta T2P 2H8

CONTACT: J. Bryan Mercer, Head, Remote Sensing, Environmental Research Section

TELEPHONE: (403) 231-6043

PROJECT TEAM: J.B. Mercer, R.S. Routledge, P.R. Brown, plus contractors

SUMMARY:

Description

Ice information system used to assist in synthesizing overall pictures of ice conditions at multiple offshore sites in the Beaufort Sea. Such sites are equipped with smart terminals capable of:

(a) accepting alphanumeric or graphical input information

(b) exchanging information with a similar shorebase terminal via a two-way data link

(c) running any of several floe drift prediction models appropriate to summer conditions

(d) displaying current and predicted conditions in the form of colour-and-texture-coded, annotated ice maps

Status

Operational, with terminals on two drillships and at shorebase.

Development

Extension of system to all Dome drillships is anticipated.

Major Equipment

Each site is equipped with a DEC PDP 11/23 based minicomputer system, augmented by a Tektronix 4027 or 4113 colour graphics display unit with a digitizing tablet.

Availability

SIAM is a Dome proprietary system. Procurement of SIAM or closely related systems by third parties from the SIAM development contractor may be negotiated with Dome.

TITLE: Radar Image Display System (RIDS)

KEYWORDS: radar, bright display, enhancement

ORGANIZATION: Dome Petroleum Limited, P.O. Box 200, Calgary, Alberta T2P 2H8

CONTACT: J. Bryan Mercer, Head, Remote Sensing, Environmental Research Section

TELEPHONE: (403) 231-6043

PROJECT TEAM: J.B. Mercer, R.S. Routledge, P.R. Brown, plus contractors

SUMMARY:

Description

Aim - to achieve improved ice detection and interpretability in a variety of conditions using marine radar in support of drilling operations; furthermore, to facilitate operational utility through a number of features including storage and recall, target tracking, etc.

Method - RIDS is a computer based system which digitizes radar video, scan converts, processes, stores and displays (in colour-coded form) the radar information.

Status - a prototype system has now been implemented in an operational configuration. Developmental work is ongoing.

Development

Production of several more systems is anticipated.

Major Equipment

DEC PDP 11/23 minicomputer, Winchester disk, colour monitor, and custom hardware.

Availability

RIDS is a Dome proprietary system. Purchase or lease of RIDS or similar systems may be negotiated with Dome or its contractor, Intera.

TITLE: Ice Resistant Real-Time Oceanographic Buoys

KEYWORDS: ice resistant, oceanographic instrumentation, real-time

ORGANIZATION: Dome Petroleum Limited, P.O. Box 200, Calgary, Alberta T2P 2H8

CONTACT: J. B. Mercer, R.S. Routledge, D. Trobak, plus contractors

TELEPHONE: (403) 260-5100

PROJECT TEAM: J. B. Mercer, R.S. Routledge, D. Trobak, plus contractor

SUMMARY:

Description

Aim - to provide real-time oceanographic data to a shipborne computer-based ice drift prediction model in support of offshore drilling operations; furthermore, to survive impact and rollover by shallow draught multi-year and first-year ice floes in the Beaufort Sea.

Method - strings of oceanographic instruments, including an integral 5 meter current meter are suspended below a specially designed spar buoy. Data from the instruments are stored and transmitted via a telemetry link to the shipboard receiver. The telemetry link utilizes handshaking and error-correction protocols for reliable operation during severe conditions.

Status - prototype systems have been in operation since 1981. Extensive modifications to mooring system and telemetry link to be trialled in 1983.

Development - spar buoy, mooring system, transmitter, receiver, micro-computer, oceanographic instruments.

Availability - immediate, to be marketed by Seakem Oceanography, Ltd., Sidney, B.C.

TITLE: Bi-level Marine Radar

KEYWORDS: ice, radar, extended range

ORGANIZATION: Dome Petroleum Limited, P.O. Box 200, Calgary, Alberta T2P 2H8

CONTACT: J. Bryan Mercer, Head, Remote Sensing, Environmental Research Section

TELEPHONE: (403) 231-6043

PROJECT TEAM: J.B. Mercer, R.S. Routledge, P.R. Brown, plus contractors

SUMMARY

Description

Aim - to achieve improved detection of low-lying sea ice at ranges up to 15 n.mi.

Method - reconfiguration of standard marine radar equipment was carried out to overcome losses due to long cable runs. Derrick top equipment was fitted with special features necessary for compliance with safety regulations. System used in conjunction with 'normal' ships radar. Synthesis of bi-level systems achieved with RIDS (see separate description).

Status - Dome has 4 systems deployed and a fifth is being installed.

Major Equipment - Modified X-Band marine radar.

Appendix II
World Meteorological Organization
Sea Ice and Iceberg Nomenclature

PART I

ICE TERMS ARRANGED BY SUBJECT

1. FLOATING ICE: Any form of ice found floating in water. The principal kinds of floating ice are *lake ice*, *river ice*, and *sea ice* which form by the freezing of water at the surface, and *glacier ice (ice of land origin)* formed on land or in an *ice shelf*. The concept includes ice that is stranded or grounded.

1.1 **Sea ice:** Any form of ice found at sea which has originated from the freezing of sea water.

1.2 **Ice of land origin:** Ice formed on land or in an *ice shelf*, found floating in water. The concept includes ice that is stranded or grounded.

1.3 **Lake ice:** Ice formed on a lake, regardless of observed location.

1.4 **River ice:** Ice formed on a river, regardless of observed location.

2. DEVELOPMENT

2.1 **New ice:** A general term for recently formed ice which includes *frazil ice*, *grease ice*, *slush* and *shuga*. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

2.1.1 FRAZIL ICE: Fine spicules or plates of ice, suspended in water.

2.1.2 GREASE ICE: A later stage of freezing than *frazil ice* when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance.

2.1.3 SLUSH: Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

2.1.4 SHUGA: An accumulation of spongy white ice lumps, a few centimetres across; they are formed from *grease ice* or *slush* and sometimes from *anchor ice* rising to the surface.

2.2 **Nilas:** A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" *(finger rafting)*. Has a matt surface and is up to 10 cm in thickness. May be subdivided into *dark nilas* and *light nilas*.

2.2.1 DARK NILAS: *Nilas* which is under 5 cm in thickness and is very dark in colour.

2.2.2 LIGHT NILAS: *Nilas* which is more than 5 cm in thickness and rather lighter in colour than *dark nilas*.

2.2.3 ICE RIND: A brittle shiny crust of ice formed on a quiet surface by direct freezing or from *grease ice*, usually in water of low salinity. Thickness to about 5 cm. Easily broken by wind or swell, commonly breaking in rectangular pieces.

2.3 **Pancake ice:** cf. 4.3.1.

2.4 **Young ice:** Ice in the transition stage between *nilas* and *first-year ice*, 10–30 cm in thickness. May be subdivided into *grey ice* and *grey-white ice*.

2.4.1 GREY ICE: *Young ice* 10–15 cm thick. Less elastic than *nilas* and breaks on swell. Usually rafts under pressure.

2.4.2 GREY-WHITE ICE: *Young ice* 15–30 cm thick. Under pressure more likely to ridge than to raft.

2.5 **First-year ice:** *Sea ice* of not more than one winter's growth, developing from *young ice*; thickness 30 cm – 2 m. May be subdivided into *thin first-year ice* / white ice, *medium first-year ice* and *thick first-year ice*.

2.5.1 THIN FIRST-YEAR ICE/WHITE ICE: *First-year ice* 30–70 cm thick.

2.5.2 MEDIUM FIRST-YEAR ICE: *First-year ice* 70–120 cm *thick*.

2.5.3 THICK FIRST-YEAR ICE: *First-year ice* over 120 cm thick.

2.6 **Old ice:** *Sea ice* which has survived at least one summer's melt. Most topographic features are smoother than on *first-year ice*. May be subdivided into *second-year ice* and *multi-year ice*.

2.6.1 SECOND-YEAR ICE: *Old ice* which has survived only one summer's melt. Because it is thicker and less dense than *first-year ice*, it stands higher out of the water. In contrast to *multi-year ice*, summer melting produces a regular pattern of numerous small *puddles*. Bare patches and puddles are usually greenish-blue.

2.6.2 MULTI-YEAR ICE: *Old ice* up to 3 m or more thick which has survived at least two summers' melt. *Hummocks* even smoother than in *second-year ice*, and the ice is almost salt-free. Colour, where bare, is usually blue. Melt pattern consists

of large interconnecting irregular *puddles* and a well-developed drainage system.

3. FORMS OF FAST ICE

3.1 **Fast ice:** *Sea ice* which forms and remains fast along the coast, where it is attached to the shore, to an *ice wall*, to an *ice front*, between shoals or grounded *icebergs*. Vertical fluctuations may be observed during changes of sea-level. Fast ice may be formed *in situ* from sea water or by freezing of *pack ice* of any age to the shore, and it may extend a few metres or several hundred kilometres from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category *(old, second-year,* or *multi-year)*. If it is thicker than about 2 m above sea-level it is called an *ice shelf*.

3.1.1 YOUNG COASTAL ICE: The initial stage of *fast ice* formation consisting of *nilas* or *young ice*, its width varying from a few metres up to 100–200 m from the shoreline.

3.2 **Icefoot:** A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the *fast ice* has moved away.

3.3 **Anchor ice:** Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation.

3.4 **Grounded ice:** *Floating ice* which is aground in shoal water (cf. *stranded ice*).

3.4.1 STRANDED ICE: Ice which has been floating and has been deposited on the shore by retreating high water.

3.4.2 GROUNDED HUMMOCK: Hummocked *grounded ice* formation. There are single grounded *hummocks* and lines (or chains) of grounded *hummocks*.

4. PACK ICE: Term used in a wide sense to include any area of *sea ice*, other than *fast ice*, no matter what form it takes or how it is disposed.

4.1 **Ice cover:** The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic local; this local may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

4.2 **Concentration:** The ratio expressed in tenths or oktas describing the mean areal density of ice in a given area.

4.2.1 COMPACT PACK ICE: *Pack ice* in which the *concentration* is 10/10 (8/8) and no water is visible.

4.2.1.1 *Consolidated pack ice: Pack ice* in which the *concentration* is 10/10 (8/8) and the *floes* are frozen together.

4.2.2 VERY CLOSE PACK ICE: *Pack ice* in which the *concentration* is 9/10 to less than 10/10 (7/8 to less than 8/8).

4.2.3 CLOSE PACK ICE: *Pack ice* in which the *concentration* is 7/10 to 8/10 (6/8 to less than 7/8), composed of *floes* mostly in contact.

4.2.4 OPEN PACK ICE: *Pack ice* in which the ice *concentration* is 4/10 to 6/10 (3/8 to less than 6/8), with many *leads* and *polynyas*, and the *floes* are generally not in contact with one another.

4.2.5 VERY OPEN PACK ICE: *Pack ice* in which the *concentration* is 1/10 to 3/10 (1/8 to less than 3/8) and water preponderates over ice.

4.2.6 OPEN WATER: A large area of freely navigable water in which *sea ice* is present in *concentrations* less than 1/10 (1/8). There may be *ice of land origin* present, although the total *concentration* of all ice shall not exceed 1/10 (1/8).

4.2.7 BERGY WATER: An area of freely navigable water with no *sea ice* present but in which *ice of land origin* is present.

4.2.8 ICE-FREE: No ice present. If ice of any kind is present this term should not be used.

4.3 **Forms of floating ice**

4.3.1 PANCAKE ICE: Predominantly circular pieces of ice from 30 cm – 3 m in diameter, and up to about 10 cm in thickness, with raised rims due to the pieces striking against one another. It may be formed on a slight swell from *grease ice*, *shuga* or *slush* or as a result of the breaking of *ice rind*, *nilas* or, under severe conditions of swell or waves, of *grey ice*. It also sometimes forms at some depth, at an interface between water bodies of different physical characteristics, from where it floats to the surface; its appearance may rapidly cover wide areas of water.

4.3.2 FLOE: Any relatively flat piece of *sea ice* 20 m or more across. Floes are subdivided according to horizontal extent as follows:

4.3.2.1 *Giant:* Over 10 km across.

4.3.2.2 *Vast:* 2–10 km across.

4.3.2.3 *Big:* 500–2,000 m across.

4.3.2.4 *Medium:* 100–500 m across.

4.3.2.5 *Small:* 20–100 m across.

4.3.3 ICE CAKE: Any relatively flat piece of *sea ice* less than 20 m across.

4.3.3.1 *Small ice cake:* An *ice cake* less than 2 m across.

4.3.4 FLOEBERG: A massive piece of *sea ice* composed of a *hummock*, or a group of *hummocks*, frozen together and separated from any ice surroundings. It may float up to 5 m above sea-level.

4.3.5 ICE BRECCIA: Ice pieces of different age frozen together.

4.3.6 BRASH ICE: Accumulations of *floating ice* made up of fragments not more than 2 m across, the wreckage of other forms of ice.

4.3.7 ICEBERG: cf. 10.4.2.

4.3.8 GLACIER BERG: cf. 10.4.2.1.

4.3.9 TABULAR BERG: cf. 10.4.2.2.

4.3.10 ICE ISLAND: cf. 10.4.3.

4.3.11 BERGY BIT: cf. 10.4.4.

4.3.12 GROWLER: cf. 10.4.5.

4.4 **Arrangement**

4.4.1 ICE FIELD: Area of *pack ice* consisting of any size of *floes*, which is greater than 10 km across (cf. *patch*).

4.4.1.1 *Large ice field:* An *ice field* over 20 km across.

4.4.1.2 *Medium ice field:* An *ice field* 15–20 km across.

4.4.1.3 *Small ice field:* An *ice field* 10–15 km across.

4.4.1.4 *Ice patch:* An area of *pack ice* less than 10 km across.

4.4.2 ICE MASSIF: A concentration of *sea ice* covering hundreds of square kilometres, which is found in the same region every summer.

4.4.3 BELT: A large feature of *pack ice* arrangement; longer than it is wide; from 1 km to more than 100 km in width.

4.4.4 TONGUE: A projection of the ice edge up to several kilometres in length, caused by wind or current.

4.4.5 STRIP: Long narrow area of *pack ice*, about 1 km or less in width, usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell or current.

4.4.6 BIGHT: An extensive crescent-shaped indentation in the *ice edge*, formed by either wind or current.

4.4.7 ICE JAM: An accumulation of broken *river ice* or *sea ice* caught in a narrow channel.

4.4.8 ICE EDGE: The demarcation at any given time between the open sea and *sea ice* of any kind, whether fast or drifting. It may be termed *compacted* or *diffuse* (cf. *ice boundary*).

4.4.8.1 *Compacted ice edge:* Close, clear-cut *ice edge* compacted by wind or current; usually on the windward side of an area of *pack ice*.

4.4.8.2 *Diffuse ice edge:* Poorly defined *ice edge* limiting an area of dispersed ice; usually on the leeward side of an area of *pack ice*.

4.4.8.3 *Ice limit:* Climatological term referring to the extreme minimum or extreme maximum extent of the *ice edge* in any given month or period based on observations over a number of years. Term should be preceded by minimum or maximum (cf. *mean ice edge*).

4.4.8.4 *Mean ice edge:* Average position of the *ice edge* in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge and mean minimum ice edge (cf. *ice limit*).

4.4.8.5 *Fast-ice edge:* The demarcation at any given time between *fast ice* and *open water*.

4.4.9 ICE BOUNDARY: The demarcation at any given time between *fast ice* and *pack ice* or between areas of *pack ice* of different *concentrations* (cf. ice edge).

4.4.9.1 *Fast-ice boundary:* The *ice boundary* at any given time between *fast ice* and *pack ice*.

4.4.9.2 *Concentration boundary:* A line approximating the transition between two areas of *pack ice* with distinctly different *concentrations*.

4.4.10 ICEBERG TONGUE: cf. 10.4.2.3.

5. PACK-ICE MOTION PROCESSES

5.1 **Diverging:** *Ice fields* or *floes* in an area are subjected to diverging or dispersive motion, thus reducing ice *concentration* and/or relieving stresses in the ice.

5.2 **Compacting:** Pieces of *floating ice* are said to be compacting when they are subjected to a converging motion, which increases ice *concentration* and/or produces stresses which may result in ice deformation.

5.3 **Shearing:** An area of *pack ice* is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a *flaw* (q.v.).

6. DEFORMATION PROCESSES

6.1 **Fracturing:** Pressure process whereby ice is permanently deformed, and rupture occurs. Most commonly used to describe breaking across *very close pack ice*, *compact pack ice* and *consolidated pack ice*.

6.2 **Hummocking:** The pressure process by which *sea ice* is forced into *hummocks*. When the floes rotate in the process it is termed screwing.

6.3 **Ridging:** The pressure process by which *sea ice* is forced into *ridges*.

6.4 **Rafting:** Pressure processes whereby one piece of ice overrides another. Most common in *new* and *young ice* (cf. *finger rafting*).

6.4.1 FINGER RAFTING: Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternately over and under the other. Common in *nilas* and *grey ice*.

6.5 **Weathering:** Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface.

7. OPENINGS IN THE ICE

7.1 **Fracture:** Any break or rupture through *very close pack ice*, *compact pack ice*, *consolidated pack ice*, *fast ice*, or a single *floe* resulting from deformation processes. Fractures may contain *brash ice* and/or be covered with *nilas* and/or *young ice*. Length may vary from a few metres to many kilometres.

7.1.1 CRACK: Any *fracture* which has not parted.

7.1.1.1 *Tide crack:* Crack at the line of junction between an immovable *ice foot* or *ice wall* and *fast ice*, the latter subject to rise and fall of the tide.

7.1.1.2 *Flaw:* A narrow separation zone between *pack ice* and *fast ice*, where the pieces of ice are in chaotic state; it forms when pack ice shears under the effect of a strong wind or current along the *fast ice boundary* (cf. *shearing*).

7.1.2 VERY SMALL FRACTURE: 0 to 50 m wide.

7.1.3 SMALL FRACTURE: 50 to 200 m wide.

7.1.4 MEDIUM FRACTURE: 200 to 500 m wide.

7.1.5 LARGE FRACTURE: More than 500 m wide.

7.2 **Fracture zone:** An area which has a great number of fractures.

7.3 **Lead:** Any *fracture* or passage-way through *sea ice* which is navigable by surface vessels.

7.3.1 SHORE LEAD: A *lead* between *pack ice* and the shore or between *pack ice* and an *ice front*.

7.3.2 FLAW LEAD: A passage-way between *pack-ice* and *fast ice* which is navigable by surface vessels.

7.4 **Polynya:** Any non-linear shaped opening enclosed in ice. Polynyas may contain *brash ice* and/or be covered with *new ice*, *nilas* or *young ice;* submariners refer to these as *skylights*. Sometimes the polynya is limited on one side by the coast and is called a *shore polynya* or by *fast ice* and is called a *flaw polynya*. If it recurs in the same position every year, it is called a *recurring polynya*.

7.4.1 SHORE POLYNYA: A *polynya* between *pack ice* and the coast or between *pack ice* and an *ice front*.

7.4.2 FLAW POLYNYA: A *polynya* between *pack ice* and *fast ice*.

7.4.3 RECURRING POLYNYA: A *polynya* which recurs in the same position every year.

8. ICE-SURFACE FEATURES

8.1 **Level ice:** *Sea ice* which is unaffected by deformation.

8.2 **Deformed ice:** A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are *rafted ice*, *ridged ice* and *hummocked ice*.

8.2.1 RAFTED ICE: Type of *deformed ice* formed by one piece of ice overriding another (cf. *finger rafting*).

8.2.1.1 *Finger rafted ice:* Type of *rafted ice* in which *floes* thrust "fingers" alternately over and under the other.

8.2.2 RIDGE: A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an *ice keel*.

8 2 2.1 *New ridge: Ridge* newly formed with sharp peaks and slope of sides usually 40°. Fragments are visible from the air at low altitude.

8.2.2.2 *Weathered ridge: Ridge* with peaks slightly rounded and slope of sides usually 30° to 40°. Individual fragments are not discernible.

8 2.2.3 *Very weathered ridge: Ridge* with tops very rounded, slope of sides usually 20°–30°.

8 2 2.4 *Aged ridge: Ridge* which has undergone considerable weathering. These ridges are best described as undulations.

8.2.2.5 *Consolidated ridge:* A *ridge* in which the base has frozen together.

8.2 2.6 *Ridged ice:* Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice (cf. *ridging*).

8.2.2.6.1 *Ridged ice zone:* An area in which much *ridged ice* with similar characteristics has formed.

8 2.3 HUMMOCK: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a *bummock*.

8.2 3.1 *Hummocked ice: Sea ice* piled haphazardly one piece over another to form an uneven surface. When weathered, has the appearance of smooth hillocks.

8.3 **Standing floe:** A separate *floe* standing vertically or inclined and enclosed by rather smooth ice.

8 4 **Ram:** An underwater ice projection from an *ice wall*, *ice front*, *iceberg* or *floe*. Its formation is usually due to a more intensive melting and erosion of the unsubmerged part.

8.5 **Bare ice:** Ice without snow cover.

8.6 **Snow-covered ice:** Ice covered with snow.

8.6.1 SASTRUGI: Sharp, irregular ridges formed on a snow surface by wind erosion and deposition. On mobile *floating ice* the ridges are parallel to the direction of the prevailing wind at the time they were formed.

8.6 2 SNOWDRIFT: An accumulation of wind-blown snow deposited in the lee of obstructions or heaped by wind eddies. A crescent-shaped snowdrift, with ends pointing down-wind, is known as a snow barchan.

9. STAGES OF MELTING

9.1 **Puddle:** An accumulation on ice of melt-water, mainly due to melting snow, but in the more advanced stages also to the melting of ice. Initial stage consists of patches of melted snow.

9.2 **Thaw holes:** Vertical holes in *sea ice* formed when surface *puddles* melt through to the underlying water.

9.3 **Dried ice:** *Sea ice* from the surface of which melt-water has disappeared after the formation of *cracks* and *thaw holes*. During the period of drying, the surface whitens.

9.4 **Rotten ice:** *Sea ice* which has become honeycombed and which is in an advanced state of disintegration.

9.5 **Flooded ice:** *Sea ice* which has been flooded by melt-water or river water and is heavily loaded by water and wet snow.

10. ICE OF LAND ORIGIN

10.! **Firn:** Old snow which has recrystallized into a dense material. Unlike snow, the particles are to some extent joined together; but, unlike ice, the air spaces in it still connect with each other.

10.2 **Glacier ice:** Ice in, or originating from, a *glacier*, whether on land or floating on the sea as *icebergs*, *bergy bits* or *growlers*.

10.2.1 GLACIER: A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principal forms of glacier are: inland ice sheets, *ice shelves*, *ice streams*, ice caps, ice piedmonts, cirque glaciers and various types of mountain (valley) glaciers.

10.2.2 ICE WALL: An ice cliff forming the seaward margin of a *glacier* which is not afloat. An ice wall is aground, the rock basement being at or below sea-level (cf. *ice front*).

10.2.3 ICE STREAM: Part of an inland ice sheet in which the ice flows more rapidly and not necessarily in the same direction as the surrounding ice. The margins are sometimes clearly marked by a change in direction of the surface slope but may be indistinct.

10.2.4 GLACIER TONGUE: Projecting seaward extension of a *glacier*, usually afloat. In the Antarctic, glacier tongues may extend over many tens of kilometres.

10.3 **Ice shelf:** A floating ice sheet of considerable thickness showing 2–50 m or more above sea-level, attached to the coast. Usually of great horizontal extent and with a level or gently undulating surface. Nourished by annual snow accumulation and often also by the seaward extension of land *glaciers*. Limited areas may be aground. The seaward edge is termed an *ice front* (q.v.).

10.3.1 ICE FRONT: The vertical cliff forming the seaward face of an *ice shelf* or other floating *glacier* varying in height from 2–50 m or more above sea-level (cf. *ice wall*).

10.4 **Calved ice of land origin**

10.4.1 CALVING: The breaking away of a mass of ice from an *ice wall*, *ice front* or *iceberg*.

10.4.2 ICEBERG: A massive piece of ice of greatly varying shape, more than 5 m above sea-level, which has broken away from a *glacier*, and which may be afloat or aground. Icebergs may be described as *tabular*, dome-shaped, sloping, pinnacled, weathered or *glacier bergs*.

10.4.2.1 *Glacier berg:* An irregularly shaped *iceberg*.

10.4.2.2 *Tabular berg:* A flat-topped *iceberg*. Most tabular bergs form by *calving* from an *ice shelf* and show horizontal banding (cf. *ice island*).

10.4.2.3 *Iceberg tongue:* A major accumulation of *icebergs* projecting from the coast, held in place by grounding and joined together by *fast ice*.

10.4.3 ICE ISLAND: A large piece of floating ice about 5 m above sea-level, which has broken away from an Arctic ice shelf, having a thickness of 30–50 m and an area of from a few thousand square metres to 500 sq. km or more, and usually characterized by a regularly undulating surface which gives it a ribbed appearance from the air.

10.4.4 BERGY BIT: A large piece of floating *glacier ice*, generally showing less than 5 m above sea-level but more than 1 m and normally about 100–300 sq. m in area.

10.4.5 GROWLER: Smaller piece of ice than a *bergy bit* or *floeberg*, often transparent but appearing green or almost black in colour, extending less than 1 m above the sea surface and normally occupying an area of about 20 sq. m.

11. SKY AND AIR INDICATIONS

11.1 **Water sky:** Dark streaks on the underside of low clouds, indicating the presence of water features in the vicinity of *sea ice*.

11.2 **Ice blink:** A whitish glare on low clouds above an accumulation of distant ice.

11.3 **Frost smoke:** Fog-like clouds due to contact of cold air with relatively warm water, which can appear over openings in the ice, or leeward of the *ice edge*, and which may persist while ice is forming.

12. TERMS RELATING TO SURFACE SHIPPING

12.1 **Beset:** Situation of a vessel surrounded by ice and unable to move.

12.2 **Ice-bound:** A harbour, inlet, etc. is said to be ice-bound when navigation by ships is prevented on account of ice, except possibly with the assistance of an icebreaker.

12.3 **Nip:** Ice is said to nip when it forcibly presses against a ship. A vessel so caught, though undamaged, is said to have been nipped.

12.4 **Ice under pressure:** Ice in which deformation processes are actively occurring and hence a potential impediment or danger to shipping.

12.5 **Difficult area:** A general qualitative expression to indicate, in a relative manner, that the severity of ice conditions prevailing in an area is such that navigation in it is difficult.

12.6 **Easy area:** A general qualitative expression to indicate, in a relative manner, that ice conditions prevailing in an area are such that navigation in it is not difficult.

12.7 **Iceport:** An embayment in an *ice front*, often of a temporary nature, where ships can moor alongside and unload directly onto the *ice shelf*.

13. TERMS RELATING TO SUBMARINE NAVIGATION

13.1 **Ice canopy:** *Pack ice* from the point of view of the submariner.

13.2 **Friendly ice:** From the point of view of the submariner, an *ice canopy* containing many large *skylights* or other features which permit a submarine to surface. There must be more than ten such features per 30 nautical miles (56 km) along the submarine's track.

13.3 **Hostile ice:** From the point of view of the submariner, an *ice canopy* containing no large *skylights* or other features which permit a submarine to surface.

13.4 **Bummock:** From the point of view of the submariner, a downward projection from the underside of the *ice canopy*; the counterpart of a *hummock*.

13.5 **Ice keel:** From the point of view of the submariner, a downward-projecting ridge on the underside of the *ice canopy*; the counterpart of a ridge. Ice keels may extend as much as 50 m below sea-level.

13.6 **Skylight:** From the point of view of the submariner, thin places in the *ice canopy*, usually less than 1 m thick and appearing from below as relatively light, translucent patches in dark surroundings. The under-surface of a skylight is normally flat. Skylights are called large if big enough for a submarine to attempt to surface through them (120 m), or small if not.

PART II

ICE TERMS ARRANGED IN ALPHABETICAL ORDER

Aged ridge: *Ridge* which has undergone considerable weathering. These ridges are best described as undulations (8.2.2.4).

Anchor ice: Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation (3.3).

Bare ice: Ice without snow cover (8.5).

Belt: A large feature of *pack ice* arrangement; longer than it is wide; from 1 km to more than 100 km in width (4.4.3).

Bergy bit: A large piece of floating *glacier ice*, generally showing less than 5 m above sea-level but more than 1 m and normally about 100–300 sq. m in area (10.4.4).

Beset: Situation of a vessel surrounded by ice and unable to move (12.1).

Big floe: (4.3.2.3) (see *Floe*).

Bight: An extensive crescent-shaped indentation in the *ice edge*, formed by either wind or current (4.4.6).

Brash ice: Accumulations of *floating ice* made up of fragments not more than 2 m across, the wreckage of other forms of ice (4.3.6).

Bummock: From the point of view of the submariner, a downward projection from the underside of the *ice canopy*; the counterpart of a *hummock* (13.4).

Calving: The breaking away of a mass of ice from an *ice wall*, *ice front* or *iceberg* (10.4.1).

Close pack ice: *Pack ice* in which the *concentration* is 7/10 to 8/10 (6/8 to less than 7/8), composed of *floes* mostly in contact (4.2.3).

Compacted ice edge: Close, clear-cut *ice edge* compacted by wind or current; usually on the windward side of an area of *pack ice* (4.4.8.1).

Compacting: Pieces of *floating ice* are said to be compacting when they are subjected to a converging motion, which increases ice *concentration* and/or produces stresses which may result in ice deformation (5.2).

Compact pack ice: *Pack ice* in which the *concentration is* 10/10 (8/8) and no water is visible (4.2.1).

Concentration: The ratio in tenths of the sea surface actually covered by ice to the total area of sea surface, both ice-covered and *ice-free*, at a specific location or over a defined area (4.2).

Concentration boundary: A line approximating the transition between two areas of *pack ice* with distinctly different *concentrations* (4.4.9.2).

Consolidated pack ice: *Pack ice* in which the *concentration* is 10/10 (8/8) and the *floes* are frozen together (4.2.1.1).

Consolidated ridge: A *ridge* in which the base has frozen together (8.2.2.5).

Crack: Any *fracture* which has not parted (7.1.1).

Dark nilas: *Nilas* which is under 5 cm in thickness and is very dark in colour (2.2.1).

Deformed ice: A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are *rafted ice*, *ridged ice* and *hummocked ice* (8.2).

Difficult area: A general qualitative expression to indicate, in a relative manner, that the severity of ice conditions prevailing in an area is such that navigation in it is difficult (12.5).

Diffuse ice edge: Poorly defined *ice edge* limiting an area of dispersed ice; usually on the leeward side of an area of *pack ice* (4.4.8.2).

Diverging: *Ice fields* or *floes* in an area are subjected to diverging or dispersive motion, thus reducing ice *concentration* and/or relieving stresses in the ice (5.1).

Dried ice: *Sea ice* from the surface of which melt-water has disappeared after the formation of *cracks* and *thaw holes*. During the period of drying, the surface whitens (9.3).

Easy area: A general qualitative expression to indicate, in a relative manner, that ice conditions prevailing in an area are such that navigation in it is not difficult (12.6).

Fast ice: *Sea ice* which forms and remains fast along the coast, where it is attached to the shore, to an *ice wall*, to an *ice front*, between shoals or grounded *icebergs*. Vertical fluctuations may be observed during changes of sea-level. Fast ice may be formed *in situ* from sea water or by freezing of *pack ice* of any age to the shore, and it may extend a few metres or several hundred kilometres from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category (*old*, *second-year*, or *multi-year*). If it is thicker than about 2 m above sea-level it is called an *ice shelf* (3.1).

Fast-ice boundary: The *ice boundary* at any given time between *fast ice* and *pack ice* (4.4.9.1).

Fast-ice edge: The demarcation at any given time between *fast ice* and *open water* (4.4.8.5).

Finger rafted ice: Type of *rafted ice* in which *floes* thrust "fingers" alternately over and under the other (8.2.1.1).

Finger rafting: Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternately over and under the other. Common in *nilas* and *grey ice* (6.4.1).

Firn: Old snow which has recrystallized into a dense material. Unlike snow, the particles are to some extent joined together; but, unlike ice, the air spaces in it still connect with each other (10.1).

First-year ice: *Sea ice* of not more than one winter's growth, developing from *young ice*; thickness 30 cm – 2 m. May be subdivided into *thin first-year ice* / white ice, *medium first-year ice* and *thick first-year ice* (2.5).

Flaw: A narrow separation zone between *pack ice* and *fast ice*, where the pieces of ice are in chaotic state; it forms when pack ice shears under the effect of a strong wind or current along the *fast ice boundary* (7.1.1.2) (cf. *shearing*).

Flaw lead: A passage-way between *pack-ice* and *fast ice* which is navigable by surface vessels (7.3.2).

Flaw polynya: A *polynya* between *pack ice* and *fast ice* (7.4.2)

Floating ice: Any form of ice found floating in water. The principal kinds of floating ice are *lake ice*, *river ice*, and *sea ice*, which form by the freezing of water at the surface, and *glacier ice (ice of land origin)* formed on land or in an *ice shelf*. The concept includes ice that is stranded or grounded (1.).

Floe: Any relatively flat piece of *sea ice* 20 m or more across. Floes are subdivided according to horizontal extent as follows (4.3.2):

GIANT: Over 10 km across (4.3.2.1).
VAST: 2–10 km across (4.3.2.2).
BIG: 500–2,000 m across (4.3.2.3).
MEDIUM: 100–500 m across (4.3.2.4).
SMALL: 20–100 m across (4.3.2.5).

Floeberg: A massive piece of *sea ice* composed of a *hummock*, or a group of *hummocks*, frozen together and separated from any ice surroundings. It may float up to 5 m above sea-level (4.3.4).

Flooded ice: *Sea ice* which has been flooded by melt-water or river water and is heavily loaded by water and wet snow (9.5).

Fracture: Any break or rupture through *very close pack ice*, *compact pack ice*, *consolidated pack-ice*, *fast ice*, or a single *floe* resulting from deformation processes. Fractures may contain *brash ice* and/or be covered with *nilas* and/or *young ice*. Length may vary from a few metres to many kilometres (7.1).

Fracture zone: An area which has a great number of fractures (7.2).

Fracturing: Pressure process whereby ice is permanently deformed, and rupture occurs. Most commonly used to describe breaking across *very close pack ice*, *compact pack ice* and *consolidated pack ice* (6.1).

Frazil ice: Fine spicules or plates of ice, suspended in water (2.1.1).

Friendly ice: From the point of view of the submariner, an *ice canopy* containing many large *skylights* or other features which permit a submarine to surface. There must be more than ten such features per 30 nautical miles (56 km) along the submarine's track (13.2).

Frost smoke: Fog-like clouds due to contact of cold air with relatively warm water, which can appear over openings in the ice, or leeward of the *ice edge*, and which may persist while ice is forming (11.3).

Giant floe: (4.3.2.1) (see *Floe*).

Glacier: A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principal forms of glacier are: inland ice sheets, *ice shelves*, *ice streams*, ice caps, ice piedmonts, cirque glaciers and various types of mountain (valley) glaciers (10.2.1).

Glacier berg: An irregularly shaped *iceberg* (10.4.2.1).

Glacier ice: Ice in, or originating from, a *glacier*, whether on land or floating on the sea as *icebergs*, *bergy bits* or *growlers* (10.2).

Glacier tongue: Projecting seaward extension of a *glacier*, usually afloat. In the Antarctic glacier tongues may extend over many tens of kilometres (10.2.4).

Grease ice: A later stage of freezing than *frazil ice* when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance (2.1.2).

Grey ice: *Young ice* 10–15 cm thick. Less elastic than *nilas* and breaks on swell. Usually rafts under pressure (2.4.1).

Grey-white ice: *Young ice* 15-30 cm thick. Under pressure more likely to ridge than to raft (2.4.2).

Grounded hummock: Hummocked *grounded ice* formation. There are single grounded *hummocks* and lines (or chains) of grounded *hummocks* (3.4.2).

Grounded ice: *Floating ice* which is aground in shoal water (3.4) (cf. stranded ice).

Growler: Smaller piece of ice than a *bergy bit* or *floeberg*, often transparent but appearing green or almost black in colour, extending less than 1 m above the sea surface and normally occupying an area of about 20 sq. m (10.4.5).

Hostile ice: From the point of view of the submariner, an *ice canopy* containing no large *skylights* or other features which permit a submarine to surface (13.3).

Hummock: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a *bummock* (8.2.3).

Hummocked ice: *Sea ice* piled haphazardly one piece over another to form an uneven surface. When weathered, has the appearance of smooth hillocks (8.2.3.1).

Hummocking: The pressure process by which *sea ice* is forced into *hummocks*. When the floes rotate in the process it is termed screwing (6.2).

Iceberg: A massive piece of ice of greatly varying shape, more than 5 m above sea-level, which has broken away from a *glacier*, and which may be afloat or aground. Icebergs may be described as *tabular*, dome-shaped, sloping, pinnacled, weathered or *glacier bergs* (10.4.2).

Iceberg tongue: A major accumulation of *icebergs* projecting from the coast, held in place by grounding and joined together by *fast ice* (10.4.2.3).

Ice blink: A whitish glare on low clouds above an accumulation of distant ice (11.2).

Ice-bound: A harbour, inlet, etc., is said to be ice-bound when navigation by ships is prevented on account of ice, except possibly with the assistance of an icebreaker (12.2).

Ice boundary: The demarcation at any given time between *fast ice* and *pack ice* or between areas of *pack ice* of different *concentrations* (4.4.9) (cf. ice edge).

Ice breccia: Ice pieces of different age frozen together (4.3.5).

Ice cake: Any relatively flat piece of *sea ice* less than 20 m across (4.3.3).

Ice canopy: *Pack ice* from the point of view of the submariner (13.1).

Ice cover: The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic local; this local may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea (4.1).

Ice edge: The demarcation at any given time between the open sea and *sea ice* of any kind, whether fast or drifting. It may be termed *compacted* or *diffuse* (4.4.8) (cf. *ice boundary*).

Ice field: Area of *pack ice* consisting of any size of *floes*, which is greater than 10 km across (4.4.1) (cf. *patch*).

Icefoot: A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the *fast ice* has moved away (3.2).

Ice-free: No *sea ice* present. There may be some *ice of land origin* (4.2.7) (cf. *open water*).

Ice front: The vertical cliff forming the seaward face of an *ice shelf* or other floating *glacier* varying in height from 2–50 m or more above sea-level (10.3.1) (cf. *ice wall*).

Ice island: A large piece of floating ice about 5 m above sea-level, which has broken away from an Arctic ice shelf, having a thickness of 30–50 m and an area of from a few thousand square metres to 500 sq km. or more, and usually characterized by a regularly undulating surface which gives it a ribbed appearance from the air (10.4.3).

Ice jam: An accumulation of broken *river ice* or *sea ice* caught in a narrow channel (4.4.7).

Ice keel: From the point of view of the submariner, a downward-projecting ridge on the underside of the *ice canopy*; the counterpart of a ridge. Ice keels may extend as much as 50 m below sea-level (13.5).

Ice limit: Climatological term referring to the extreme minimum or extreme maximum extent of the *ice edge* in any given month or period based on observations over a number of years. Term should be preceded by minimum or maximum (4.4.8.3) (cf. *mean ice edge*).

Ice massif: A concentration of *sea ice* covering hundreds of square kilometres, which is found in the same region every summer (4.4.2).

Ice of land origin: Ice formed on land or in an *ice shelf*, found floating in water. The concept includes ice that is stranded or grounded (1.2).

Ice patch: An area of *pack ice* less than 10 km across (4.4.1.4).

Ice port: An embayment in an *ice front*, often of a temporary nature, where ships can moor alongside and unload directly onto the ice shelf (12.7).

Ice rind: A brittle shiny crust of ice formed on a quiet surface by direct freezing or from *grease ice*, usually in water of low salinity. Thickness to about 5 cm. Easily broken by wind or swell, commonly breaking in rectangular pieces (2.2.3).

Ice shelf: A floating ice sheet of considerable thickness showing 2–50 m or more above sea-level, attached to the coast. Usually of great horizontal extent and with a level or gently undulating surface. Nourished by annual snow accumulation and often also by the seaward extension of land *glaciers*. Limited areas may be aground. The seaward edge is termed an *ice front* (q.v.) (10.3).

Ice stream: Part of an inland ice sheet in which the ice flows more rapidly and not necessarily in the same direction as the surrounding ice. The margins are sometimes clearly marked by a change in direction of the surface slope but may be indistinct (10.2 3).

Ice under pressure: Ice in which deformation processes are actively occurring and hence a potential impediment or danger to shipping (12.4).

Ice wall: An ice cliff forming the seaward margin of a *glacier* which is not afloat. An ice wall is aground, the rock basement being at or below sea-level (10.2.2) (cf. *ice front*).

Lake ice: Ice formed on a lake, regardless of observed location (1.3).

Large fracture: More than 500 m wide (7.1.5).

Large ice field: An *ice field* over 20 km across (4.4.1.1).

Lead: Any *fracture* or passage-way through *sea ice* which is navigable by surface vessels (7.3).

Level ice: *Sea ice* which is unaffected by deformation (8.1)

Light nilas: *Nilas* which is more than 5 cm in thickness and rather lighter in colour than *dark nilas* (2.2.2).

Mean ice edge: Average position of the *ice edge* in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge and mean minimum ice edge (4.4.8.4) (cf. *ice limit*).

Medium first-year ice: *First-year ice* 70–120 cm thick (2.5.2).

Medium floe: (see *Floe*) (4.3.2.4).

Medium fracture: 200 to 500 m wide (7.1.4).

Medium ice field: An *ice field* 15–20 km across (4.4.1.2).

Multi-year ice: *Old ice* up to 3 m or more thick which has survived at least two summers' melt. *Hummocks* even smoother than in *second-year ice*, and the ice is almost salt-free. Colour, where bare, is usually blue. Melt pattern consists of large interconnecting irregular *puddles* and a well-developed drainage system (2.6.2).

New ice: A general term for recently formed ice which includes *frazil ice*, *grease ice*, *slush* and *shuga*. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat (2.1).

New ridge: *Ridge* newly formed with sharp peaks and slope of sides usually 40°. Fragments are visible from the air at low altitude (8.2.2.1).

Nilas: A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" *(finger rafting)*. Has a matt surface and is up to 10 cm in thickness. May be subdivided into *dark nilas* and *light nilas* (2.2).

Nip: Ice is said to nip when it forcibly presses against a ship. A vessel so caught, though undamaged, is said to have been nipped (12.3).

Old ice: *Sea ice* which has survived at least one summer's melt. Most topographic features are smoother than on *first-year ice*. May be subdivided into *second-year ice* and *multi-year ice* (2.6).

Open pack ice: *Pack ice* in which the ice *concentration* is 4/10 to 6/10 (3/8 to less than 6/8), with many *leads* and *polynyas*, and the *floes* are generally not in contact with one another (4.2.4).

Open water: A large area of freely navigable water in which *sea ice* is present in *concentrations* less than 1/10 (1/8). When there is no sea ice present, the area should be termed *ice-free*, even though icebergs are present (4.2.6).

Pack ice: Term used in a wide sense to include any area of *sea ice*, other than *fast ice*, no matter what form it takes or how it is disposed (4.).

Pancake ice: Predominantly circular pieces of ice from 30 cm – 3 m in diameter, and up to about 10 cm in thickness, with raised rims due to the pieces striking against one another. It may be formed on a slight swell from *grease ice*, *shuga* or *slush* or as a result of the breaking of *ice rind*, *nilas* or, under severe conditions of swell or waves, of *grey ice*. It also sometimes forms at some depth, at an interface between water bodies of different physical characteristics, from where it floats to the surface; its appearance may rapidly cover wide areas of water (4.3.1).

Polynya: Any non-linear shaped opening enclosed in ice. Polynyas may contain *brash ice* and/or be covered with *new ice*, *nilas* or *young ice*; submariners refer to these as *skylights*. Sometimes the polynya is limited on one side by the coast and is called a *shore polynya* or by *fast ice* and is called a *flaw polynya*. If it recurs in the same position every year, it is called a *recurring polynya* (7.4).

Puddle: An accumulation on ice of melt-water, mainly due to melting snow, but in the more advanced stages also to the melting of ice. Initial stage consists of patches of melted snow (9.1).

Rafted ice: Type of *deformed ice* formed by one piece of ice overriding another (8.2.1) (cf. finger rafting).

Rafting: Pressure processes whereby one piece of ice overrides another. Most common in *new* and *young ice* (6.4) (cf. *finger rafting*).

Ram: An underwater ice projection from an *ice wall*, *ice front*, *iceberg* or *floe*. Its formation is usually due to a more intensive melting and erosion of the unsubmerged part (8.4).

Recurring polynya: A *polynya* which recurs in the same position every year (7.4.3).

Ridge: A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an *ice keel* (8.2.2).

Ridged ice: Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice (8.2.2.6) (cf. *ridging*).

Ridged-ice zone: An area in which much *ridged ice* with similar characteristics has formed (8.2.2.6.1).

Ridging: The pressure process by which *sea ice* is forced into *ridges* (6.3).

River ice: Ice formed on a river, regardless of observed location (1.4).

Rotten ice: *Sea ice* which has become honeycombed and which is in an advanced state of disintegration (9.4).

Sastrugi: Sharp, irregular ridges formed on a snow surface by wind erosion and deposition. On mobile *floating ice* the ridges are parallel to the direction of the prevailing wind at the time they were formed (8.6.1).

Sea ice: Any form of ice found at sea which has originated from the freezing of sea water (1.1).

Second-year ice: *Old ice* which has survived only one summer's melt. Because it is thicker and less dense than *first-year ice*, it stands higher out of the water. In contrast to *multi-year ice*, summer melting produces a regular pattern of numerous small *puddles*. Bare patches and puddles are usually greenish-blue (2.6.1).

Shearing: An area of *pack ice* is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a *flaw* (q.v.) (5.3).

Shore lead: A *lead* between *pack ice* and the shore or between *pack ice* and an *ice front* (7.3.1).

Shore polynya: A *polynya* between *pack ice* and the coast or between *pack ice* and an *ice front* (7.4.1).

Shuga: An accumulation of spongy white ice lumps, a few centimetres across; they are formed from *grease ice* or *slush* and sometimes from *anchor ice* rising to the surface (2.1.4).

Skylight: From the point of view of the submariner, thin places in the *ice canopy*, usually less than 1 m thick and appearing from below as relatively light, translucent patches in dark surroundings. The undersurface of a skylight is normally flat. Skylights are called large if big enough for a submarine to attempt to surface through them (120 m), or small if not (13.6).

Slush: Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall (2.1.3).

Small floe: (4.3.2.5) (see *Floe*).

Small fracture: 50 to 200 m wide (7.1.3).

Small ice cake: An ice cake less than 2 m across (4.3.3.1).

Small ice field: An *ice field* 10–15 km across (4.4.1.3).

Snow-covered ice: Ice covered with snow (8.6).

Snowdrift: An accumulation of wind-blown snow deposited in the lee of obstructions or heaped by wind eddies. A crescent-shaped snowdrift, with ends pointing down-wind, is known as a snow barchan (8.6.2).

Standing floe: A separate *floe* standing vertically or inclined and enclosed by rather smooth ice (8.3).

Stranded ice: Ice which has been floating and has been deposited on the shore by retreating high water (3.4.1).

Strip: Long narrow area of *pack ice*, about 1 km or less in width, usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell or current (4.4.5).

Tabular berg: A flat-topped *iceberg*. Most tabular bergs form by *calving* from an *ice shelf* and show horizontal banding (10.4.2.2) (cf. *ice island*).

Thaw holes: Vertical holes in *sea ice* formed when surface *puddles melt through to the underlying water* (9.2).

Thick first-year ice: *First-year ice* over 120 cm thick (2.5.3).

Thin first-year ice/white ice: *First year ice* 30–70 cm thick (2.5.1).

Tide crack: Crack at the line of junction between an immovable *ice foot* or *ice wall* and *fast ice*, the latter subject to rise and fall of the tide (7.1.1.1).

Tongue: A projection of the ice edge up to several kilometres in length, caused by wind or current (4.4.4).

Vast floe: (4.3.2.2) (see *Floe*).

Very close pack ice: *Pack ice* in which the *concentration* is 9/10 to less than 10/10 (7/8 to less than 8/8) (4.2.2).

Very open pack ice: *Pack ice* in which the *concentration* is 1/10 to 3/10 (1/8 to less than 3/8) and water preponderates over ice (4.2.5).

Very small fracture: 0 to 50 m wide (7.1.2).

Very weathered ridge: *Ridge* with tops very rounded, slope of sides usually 20°–30° (8.2.2.3).

Water sky: Dark streaks on the underside of low clouds, indicating the presence of water features in the vicinity of *sea ice* (11.1).

Weathered ridge: *Ridge* with peaks slightly rounded and slope of sides usually 30° to 40°. Individual fragments are not discernible (8.2.2.2).

Weathering: Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface (6.5).

White ice: See *Thin first-year ice* (2.5.1).

Young coastal ice: The initial stage of *fast ice* formation consisting of *nilas* or *young ice*, its width varying from a few metres up to 100–200 m from the shoreline (3.1.1).

Young ice: Ice in the transition stage between *nilas* and *first-year ice*, 10–30 cm in thickness. May be subdivided into *grey ice* and *grey-white ice* (2.4).

Appendix III
Government Regulations and Guidelines
Relevant to Ice Detection/Avoidance

CANADA SHIPPING ACT

Navigating Appliances Regulations

REGULATIONS RESPECTING COMPASSESS, SOUNDING APPARATUS AND OTHER NAVIGATING APPLIANCES

PART I

Ships in Canadian Waters and Fishing Zones

Application

3. (1) Subject to subsection (2), this Part applies to all self-propelled ships carrying pollutants in

(a) Canadian waters south of the sixieth parallel of north latitude;
(b) Canadian waters north of the sixieth parallel of north latitude that are not within a shipping safety control zone prescribed pursuant to the Arctic Waters Pollution Prevention Act; and
(c) Any fishing zone of Canada prescribed pursuant to the Territorial Sea and Fishing Zones Act.

(2) Sections 5 to 13 and sections 17 and 27 do not apply to

(a) a fishing vessel that does not exceed 80 feet in length or 150 tons; or
(b) a pleasure vessel.

Compliance

4. (1) The owner of every ship shall ensure that the ship is provided with the navigating appliances and apparatus required by this Part and that such appliances and apparatus are installed in the manner and place required by this Part.

(2) Where any navigating appliance or apparatus on a ship required to be provided thereon by this Part ceases to be in an effective operating condition, the master of the ship shall ensure that such appliance or apparatus is restored to an effective operating condition as soon as possible.

Radar

18. (1) Subject to subsections (2) and (3), every ship of 500 tons or more shall be provided with a marine radar installation that

(a) complies with all the provisions of Schedule D; and
(b) is equipped with facilities for manual plotting at or close to the position of the radar display unt.

(2) Every ship of 1,600 tons of more that is a tanker or a chemical carrier shall be fitted with two marine radar installations that

(a) comply with all the provisions of Schedule D and
(b) are equipped with facilities of manual plotting at or close to the positions of each radar display unit.

(3) This section does not apply until January 1, 1974.

PART II

SHIPS IN WATERS OTHER THAN CANADIAN WATERS OR FISHING ZONES

Application

30. (1) Subject to subsection (2), this Part applies to all self-propelled Canadian ships that are in waters other than

(a) Canadian waters;
(b) any shipping safety control zone prescribed pursuant to the Arctic Waters Pollution Prevention Act; and
(c) any fishing zone of Canada prescribed pursuant to the Territorial Sea and Fishing Zones Act.

(2) Sections 32 to 43 do not apply to

(a) a fishing vessel that does not exceed 80 feet in length or 150 tons; or
(b) a pleasure vessel.

Compliance

31. (1) The owner of every ship shall ensure that the ship is provided with the navigating appliances and apparatus required by this Part and that such appliances and apparatus are installed in the manner and place required by this Part.

(2) Where any navigating appliance or apparatus on a ship required to be provided thereon by this Part ceases to be in an effective operating condition, the master of the ship shall ensure that such appliance or apparatus is restored to an effective operating condition as soon as possible.

SCHEDULE D

Radar

1. Any radar that is installed on a ship shall be able to clearly display under normal propagation conditions when the ship rolls 10 degrees to each side

(a) another ship of 5,000 tons at a range of 7 nautical miles, whatever its aspect; and

(b) an object having an echoing area of 12 square yards or 10 square metres from a minimum range of not more than 100 yards or 92 metres to a maximum range of not less than 2 nautical miles.

2. A radar that is installed on a ship shall be able to clearly display as two separate indications.

(a) on any range scale of the radar, two objects at the same range that are separated by 3 degrees in azimuth; and

(b) on the shortest range scale of the radar, two objects on the same azimuth that are separated by 75 yards or 68.25 meters.

3. Means shall be provided to minimize on the display of a radar installed on a ship any unwanted responses from precipitation and from the sea.

4. A radar that is installed on a ship shall be provided with a plan position indicator display and the ship's heading shall be represented electronically on the display.

5. Means shall be provided for measuring from the plan position indicator display.

(a) the bearing of an object displayed at a range of three quarters of a nautical mile or more with an error of not more than two degrees; and

(b) the range of an object with an error of not more than

(i) 6 per cent of that range, where the range is three-quarters of a nautical mile or more, and

(ii) 90 yards or 82 metres, where the range is less than three-quarters of a nautical mile.

6. A radar that is installed on a ship shall

(a) be capable of continuous operation;

(b) be capable of being switched on, controlled and operated from the main display position; and

(c) become fully operational

(i) within one minute after being switched on, or

(ii) where the radar is fitted with a standby circuit, within four minutes after first being switched on if the period from standby to fully operational is not more than one minute.

7. A radar installation on a ship shall

(a) not interfere with the efficiency of the compasses;

(b) be arranged to suppress, as far as practicable, radio interference between the radar installation and other navigational appliance and radio apparatus; and

(c) be arranged to limit, as far as practicable, mechanical noise.

8. The radar scanner shall be sited on a ship so that, as far as is practicable, blind arcs and reduced signal arcs are avoided.

ARCTIC WATERS POLLUTION PREVENTION ACT

Arctic Shipping Pollution Prevention Regulations

REGULATIONS RESPECTING THE PREVENTION OF POLLUTION OF ARCTIC WATERS BY SHIPS

Navigating Equipment

7. (1) Notwithstanding subsections 19(4) and (5), 20(3), 21(3) and (4) and 24(3) of the Navigating Appliances Regulations, no self-propelled ship shall navigate within any zone unless it complies with sections 4 to 13, 17 and 19 to 28 of Part I of the Navigating Appliances Regulations as if it were a ship to which Part I of those Regulations applies and within waters to which that Part applies, and unless it complies with the following standards:

(a) in the case of a ship of 500 tons, gross tonnage, or more it shall be fitted with at least one efficient gyro compass described in subsection (3);

(b) in the case of a ship that is

(i) of 1,600 tons, gross tonnage, or more and navigating in zone 1, 2, 3, 5, 6, 7, or 13.

(ii) of 5,000 tons, gross tonnage, or more and navigating in zone 4, 8, 9, 11, or 16, and

(iii) of 50,000 tons, gross tonnage, or more and navigating in zone 10, 12, 14, or 15,

it shall be fitted with at least two efficient gyro compasses described in subsection (3);

(c) in the case of a ship of 100 tons, gross tonnage, or more, it shall be fitted with at least one marine radar installation described in subsection (4).

(d) in the case of a ship of 1,600 tons, gross tonnage, or more, it shall be fitted with at least two marine radar installations described in subsection (4).

(e) in the case of a ship of 100 tons, gross tonnage, or more, it shall be fitted with at least one efficient echo sounding device;

(f) in the case of a ship of 1,600 tons, gross tonnage, or more, navigating in any zone other than zone 14, 15, or 16, it shall be fitted with at least two efficient echo sounding devices;

(g) in the case of a ship of 1,600 tons, gross tonnage, or more, it shall carry navigating instruments and publications necessary to determine compass error and positions by astronominal means; and

(h) in the case of an Arctic Class ship or a Type A ship it shall be provided with a facsimile terminal capable of receiving transmission from stations Halifax CFH and Edmonton VFE and from ice reconnaissance aircraft on the frequencies listed in the publication Radio Aids to Marine Navigation published by the Department of Transport.

(2) Every self-propelled ship shall be provided with

(a) the manufacturer's operating and maintenance manuals for the navigational appliances and apparatus required by this section; and

(b) such spare parts as are recommended to be carried by the operating and maintenance manuals referred to in paragraph (a).

(3) Every gyro compass required by paragraph (1) (a) or (b) shall

(a) provide gyro heading information at the normal steering position; and

(b) be capable of giving, according to the manufacturer's specifications, reliable heading information at the latitudes in which the ship is operating.

(4) Every marine radar installation required by paragraph (1) (c) and (d) shall

(a) comply with Schedule D to the Navigating Applicances Regulations, and

(b) be equipped with plotting facilities at or close to the position of the radar display unit.

Ice Navigator

26. (1) No tanker shall navigate within any zone without the aid of an ice navigator who is qualified in accordance with subsection (3).

(2) No ship other than a tanker shall navigate in any zone set out in the heading to each of Columns II to XVII of Schedule H

(a) where the words "No Entry" are shown in that Column of item 14, and

(b) where a period of time is shown in that Column of item 14, except during that period of time, without the aid of an ice navigator who is qualified in accordance with subsection (3).

(3) The ice navigator on a ship shall

(a) be qualified to act as master or person in charge of the deck watch in accordance with section 23; and

(b) have served in the capacity of master; person in charge of the deck watch or helmsman for a total period of at least five days while the ship on which he was serving was in ice conditions that required the ship to make extraordinary manoeuvers or be assisted by an icebreaker.

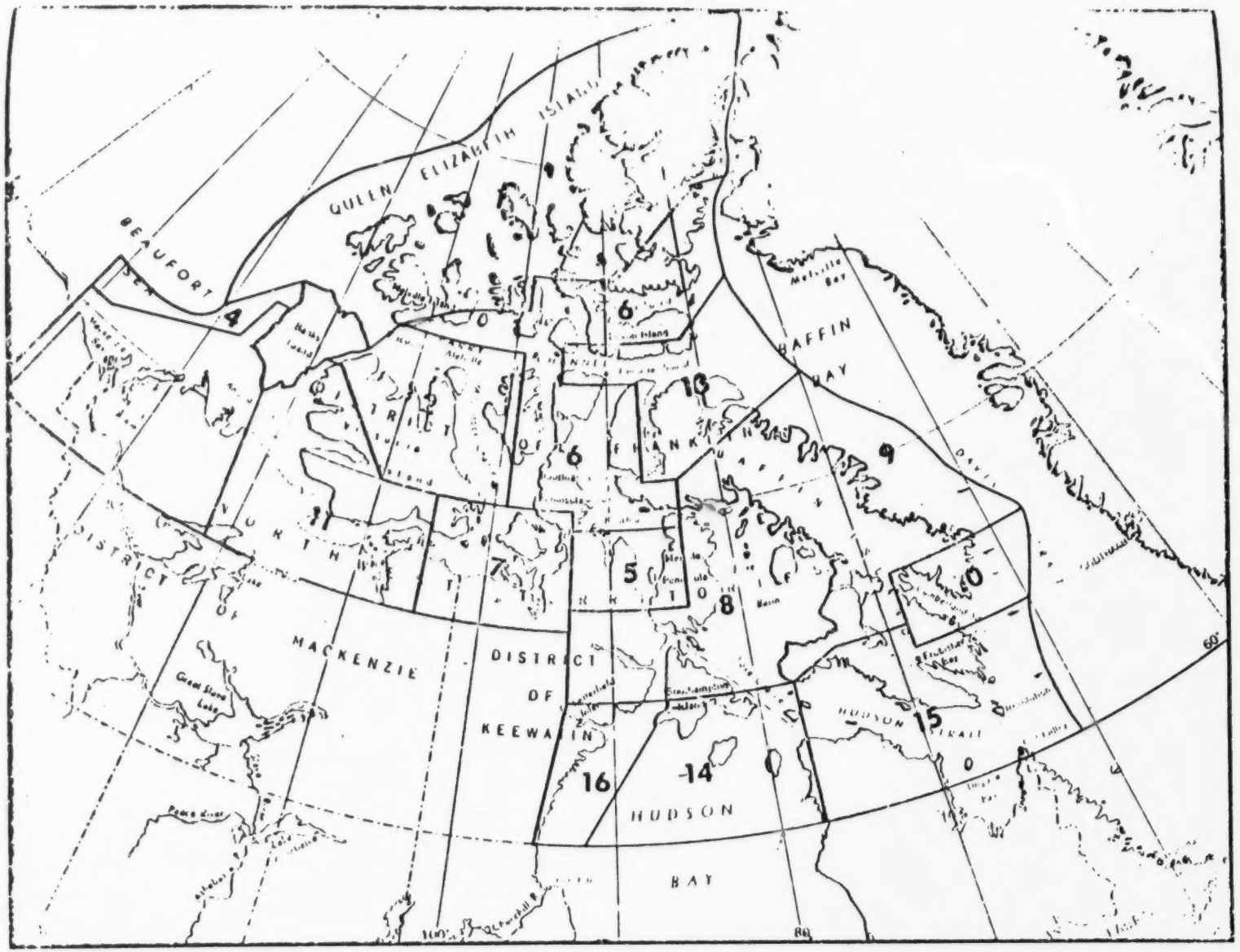
	Ice Pressures in pounds per square inch (kiloponds per square centimetre)						
	Column I	Column II	Column III	Column IV	Column V	Column VI	Column VII
Item	Arctic Class	Bow Area	Lower Bow Area	Mid-body Area	Lower Transition Area	Upper Transition Area	Stern Area
1	1	230* (17.58)	**	100* (7.03)	**	**	100* (7.03)
2	1A	400 (28.12)	210 (14.76)	260 (18.28)	180 (12.65)	130 (9.14)	325 (22.85)
3	2	600 (42.18)	320 (22.50)	400 (28.12)	260 (18.28)	200 (14.06)	500 (35.15)
4	3	800 (56.24)	420 (29.53)	530 (37.26)	370 (26.01)	260 (18.28)	660 (46.40)
5	4	1000 (70.30)	530 (37.26)	660 (46.40)	460 (32.34)	330 (23.20)	820 (57.65)
6	6	1200 (84.36)	640 (44.99)	750 (52.73)	520 (36.56)	370 (26.01)	940 (66.08)
7	7	1400 (98.42)	740 (52.02)	850 (59.76)	600 (42.18)	420 (29.53)	1050 (73.82)
8	8	1500 (105.65)	800 (56.24)	950 (66.79)	660 (46.40)	470 (33.04)	1200 (84.36)
9	10	1500 (105.65)	800 (56.24)	950 (66.79)	660 (46.40)	470 (33.04)	1200 (84.36)

*In an Arctic Class 1 ship, only that part of
(a) the bow area and stern area lying between the horizontal projections of the upper and lower edges of the mid-body area need be considered; and
(b) the mid-body area forward of amidships need be considered.
**In an Arctic Class 1 ship, ice pressure need not be considered as a factor in the design of the hull in the lower bow area, lower transition area and upper transition area, and the strength standards usually applied to ocean-going ships shall apply in these areas.

Hull Strength Standards for Arctic Class Vessels.
(Arctic Waters Pollution Prevention Act)

Schedule for movement of Arctic Class Vessels by class and zone (from Canadian Artic Waters Pollution Prevention Act).

Column I Category	Column II Zone 1	Column III Zone 2	Column IV Zone 3	Column V Zone 4	Column VI Zone 5	Column VII Zone 6	Column VIII Zone 7	Column IX Zone 8	Column X Zone 9	Column XI Zone 10	Column XII Zone 11	Column XIII Zone 12	Column XIV Zone 13	Column XV Zone 14	Column XVI Zone 15	Column XVII Zone 16
Arctic Class 10 1.	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year
Arctic Class 8 2.	Jul. 1 to Oct. 15	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year
Arctic Class 7 3.	Aug. 1 to Sept. 30	Aug. 1 to Nov. 30	Jul 1 to Dec. 31	Jul. 1 to Dec. 15	Jul. 1 to Dec. 15	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year
Arctic Class 6 4.	Aug. 15 to Sept. 15	Aug 1. to Oct. 31	Jul. 15 to Nov. 30	Jul. 15 to Nov. 30	Aug 1 to Oct 15	Jul 15 to Feb 28	Jul. 1 to Mar 31	Jul 1 to Mar 31	All Year	All Year	Jul 1 to Mar 31	All Year	All Year	All Year	All Year	All Year
Arctic Class 4 5.	Aug. 15 to Sept. 15	Aug. 15 to Oct. 15	Jul. 15 to Oct. 31	Jul. 15 to Nov. 15	Aug 15 to Sept. 30	Jul 20 to Dec. 31	Jul 15 to Jan 15	Jul 15 to Jan 15	Jul. 10 to Mar. 31	Jul 10 to Feb 28	Jul 5 to Jan 15	June 1 to Jan 31	June 1 to Feb 15	June 15 to Feb 15	June 15 to Mar 15	June 1 to Feb 15
Arctic Class 3 6.	Aug. 20 to Sept 15	Aug 20 to Sept. 30	Jul 25 to Oct. 15	Jul. 20 to Nov. 5	Aug 20 to Sept 25	Aug 1 to Nov 20	Jul 20 to Dec 15	Jul 20 to Dec 31	Jul 20 to Jan 20	Jul 15 to Jan 25	Jul 5 to Dec 15	June 10 to Dec 31	June 10 to Dec 31	June 20 to Jan 10	June 20 to Jan 31	June 5 to Jan 10
Arctic Class 2 7.	No Entry	No Entry	Aug 15 to Sept 30	Aug 1 to Oct. 31	No Entry	Aug 15 to Nov 20	Aug 1 to Nov 20	Aug 1 to Nov 30	Aug 1 to Dec 20	Jul 25 to Dec 20	Jul 10 to Nov 20	June 15 to Dec 5	June 25 to Nov 15	June 25 to Dec 10	June 25 to Dec 20	June 10 to Dec 10
Arctic Class 1A 8.	No Entry	No Entry	Aug 20 to Sept. 15	Aug 20 to Sept. 30	No Entry	Aug 25 to Oct 31	Aug 10 to Nov 5	Aug 10 to Nov 20	Aug 10 to Dec 10	Aug 1 to Dec 10	Jul 15 to Nov 10	Jul 1 to Nov 10	Jul 15 to Oct 31	Jul 1 to Nov 30	Jul 1 to Dec 10	June 20 to Nov 30
Arctic Class 1 9.	No Entry	No Entry	No Entry	No Entry	No Entry	Aug 25 to Sep. 30	Aug 10 to Oct 15	Aug 10 to Oct 31	Aug 10 to Oct 31	Aug 1 to Oct 31	Jul 15 to Oct 20	Jul 1 to Oct 31	Jul 15 to Oct 15	Jul 1 to Nov 30	Jul 1 to Nov 30	June 20 to Nov 15
Type A 10.	No Entry	No Entry	Aug 20 to Sept 10	Aug. 20 to Sept. 20	No Entry	Aug 15 to Oct 15	Aug 1 to Oct 25	Aug 1 to Nov 10	Aug 1 to Nov 20	Jul 25 to Nov 20	Jul 10 to Oct 31	June 15 to Nov 10	June 25 to Oct 22	June 25 to Nov 30	June 25 to Dec 5	June 20 to Nov 20
Type B 11	No Entry	No Entry	Aug 20 to Sept 5	Aug 20 to Sept. 15	No Entry	Aug 25 to Sep 30	Aug 10 to Oct 15	Aug 10 to Oct 31	Aug 10 to Oct 31	Aug 1 to Oct 31	Jul 15 to Oct 20	Jul 1 to Oct 25	Jul 15 to Oct 15	Jul 1 to Nov 30	Jul 1 to Nov 30	June 20 to Nov 10
Type C 12.	No Entry	No Entry	No Entry	No Entry	No Entry	Aug 25 to Sep 25	Aug 10 to Oct 10	Aug 10 to Oct 25	Aug 10 to Oct 25	Aug 1 to Oct 25	Jul 15 to Oct 15	Jul 1 to Oct. 25	Jul 15 to Oct 10	Jul 1 to Nov 25	Jul 1 to Nov 25	June 25 to Nov 10
Type D 13	No Entry	No Entry	No Entry	No Entry	No Entry	No Entry	Aug 10 to Oct 5	Aug 15 to Oct. 20	Aug 15 to Oct 20	Aug 5 to Oct 20	Jul 15 to Oct 10	Jul 1 to Oct 20	Jul 10 to Sep 30	Jul 10 to Nov 10	Jul 5 to Nov 10	Jul 1 to Oct 31
Type E 14.	No Entry	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 10 to Sep 30	Aug 20 to Oct 20	Aug 20 to Oct 15	Aug 10 to Oct 20	Jul 15 to Sep 30	Jul 1 to Oct 20	Aug 15 to Sep 2[illegible]	Jul 20 to Oct 31	Jul 20 to Nov 5	Jul 1 to Oct 31


BEAUFORT SEA
QUEEN ELIZABETH ISLANDS
BAFFIN BAY
DISTRICT OF MACKENZIE
DISTRICT OF KEEWATIN
HUDSON BAY
4
0
6
10
6
9
7
5
8
0
15
16
14
0
60°

PHYSICAL ENVIRONMENTAL GUIDELINES FOR DRILLING PROGRAMS IN THE CANADIAN OFFSHORE

These guidelines are issued in connection with the Canada Oil and Gas Drilling Regulations and in particular with sections:

7	on application for Drilling Program Approval;
31(2)	on meteorological forecasts;
79(1)	on contingency plans;
176(2)	on environmental conditions to be recorded;
179(2)	on daily weather and sea state reports; and,
228(2)	on final well reports.

In order to satisfy these sections of the Regulations an operator is to provide a description of the proposed meteorological and oceanographic data acquisition and management program in the application for Drilling Program Approval. Consultation with the appropriate authorities in advance of the application is encouraged.

These guidelines may be modified as the result of field experience, quantity and quality of data, equipment developments, etc.

Canada Oil and Gas Lands Administration
Department of Energy, Mines and Resources
Ottawa
September 1981

PHYSICAL ENVIRONMENTAL REQUIREMENTS

DATA COLLECTION

Operators are required to make meteorological and oceanographic measurements in connection with drilling operations in accordance with these guidelines unless the regulatory agency has agreed to other arrangements. The standards and procedures for collecting and reporting meteorological and oceanographic data are described below.

Parameters to be Observed or Measured

a) Wind - average speed and direction as well as gust speed and direction. The average wind speed should be the average over a one minute interval. The gust should be the maximum occurring during the fifteen minute interval preceeding the wind observation.

b) Barometric pressure - instantaneous value.

c) Air temperature - instantaneous dry bulb.

d) Dew point temperatures - instantaneous wet bulb and calculated dew point temperature.

e) Sea surface temperature - instantaneous value.

f) Sky condition - instantaneous amount, types and height of cloud.

g) Present and past weather-instantaneous.

h) Visibility-instantaneous.

i) Ice accretion - cause, thickness, and rate of ice growth on the drilling unit.

j) Sea State - instantaneous values of sea and swell height, period and direction. Wave direction may be determined visually if measured values are not available.

k) Sea ice - type (pack, iceberg etc.) concentration, stage of development, type, direction and location of ice edge, ice movement.

l) Iceberg or Ice Island positions or tracks for all bergs or islands within radar range (minimum is 20 nautical miles) are to be monitored and plotted. When a berg or island is being towed this should be indicated.

m) Iceberg or Ice Island Shape, Length, Width, Height, Draft and Mass are to be estimated for as many bergs or islands within radar range as is practically possible. The length will correspond to the length of the longest side, the width corresponds to the width of the shortest side, the height should correspond to the hightest point and the draft the lowest point. The time should be indicated when the dimensions are determined.

n) Surface ocean wave spectra - instrumentation should be located such that the wave field as observed is not disturbed by the drilling unit. The Marine Environmental Data Service (MEDS), Department of Fisheries and Oceans, Ottawa, will normally provide Datawell Waverider Buoys for wave measurements. Other instrumentation may be used but the specifications stated must be met and the recording sequence should be consistent with a twenty-minute continuous wave record every three hours and have the capability for continuous operation during storms.

o) Surface Currents (Type 1): upon the request of the Chief Conservation Officer estimates are to be made by deploying drifters of various types and monitoring their position. (The three most common types are drift cards, surface drift buoys or satellite-tracked buoys of the Nimbus/RAMS type).

p) Currents Measured from the Drilling unit (Type 2): real-time measurements from the drilling unit are to be taken at a fixed depth. In most cases this would be 20 m but this depth is subject to geometry of the drilling unit and the nature of the surface layer of the ocean. Measurements at other depths using the same instrument should be taken by the operator if required for diver support, iceberg movement prediction, or oil spill trajectory predictions.

q) Moored Current Measurements (Type 3): two moorings are required. One is to contain only a near-surface current meter at a depth of 20 m and a sub-surface buoy at a depth of 15 m. The meter on this mooring needs to have a capability for operations in the wave zone, i.e. vector averaging with a current meter that can orient its main axis or the impeller axis of rotation in the direction of the prevailing current. Another mooring is for measurements at or near mid-water depth and approximately 20 m from the bottom. The main mooring support buoy should be located 5 to 10 metres above the mid-water current meter. All moored current meters are to have a recording interval of every 20 minutes. Moorings are to be left in place for as long as possible and need not be moved with every relocation of the drilling unit in a particular area.

r) Temperature and Salinity (Conductivity): these measurements should be recorded simultaneously with all current meter measurements.

s) Tides (Pressure): tidal measurements may be required.

t) Turbidity (Underwater visibility): comments on the visibility of the water in the vicinity of the well head are required in the introduction of the well history report.

These parameters may be derived from instruments or may in some cases be determined visually. Recordings may be automatic or manual. Automatic instrumentation is preferred; however, cloud conditions, present and past weather, visibility, wave direction, sea ice and ice accretion must be determined visually and recorded in a log.

The specifications required for instrumentation used under these guidelines along with the sampling frequency required are outlined in Table 1.

Table I

SPECIFICATIONS FOR PHYSICAL ENVIRONMENTAL PARAMETERS

The specifications in the tables below are designed to ensure the consistency, accuracy and comparability of data.

Parameter	Range	Accuracy	Resolution	Frequency
Wind speed*	0-120 Knots	±10%	1.0 knot	3hr, hourly or continuous
Wind & wave direction*	0-360°	±10°	1.0°	3hr, hourly or continuous
Barometric pressure	920 to 1060 mb	±0.5mb	0.5 mb	3 hr, hourly
Air temperature	-40° to 40°C	±0.5°C	0.1°C	3 hr, hourly
Wet-Bulb temperature	-40° to 40°C	±0.5°C	0.1°C	3 hr, hourly
Dewpoint	-40° to 40°C	±0.5°C	0.5°C	3 hr, hourly
Sea Surface temperature	-5° to 25°C	±0.5°C	0.5°C	3 hr
Cloud amount, types & height	Per SAWR (Supplementary Aviation Weather Reports)			3 hr, hourly
Ice accretion	Per MANMAR (Manual of Marine Weather Obs)			3 hr
Wave height and spectra (Appendix IV)*	0-35 m	±5%	0.5 m	3 hr, or continuous
Wave period* (Appendix III)	2-25 sec	0.5 sec	0.2 sec	3 hr or continuous
Sea Ice	Per MANMAR			3 hr, hourly
Iceberg or Ice Island Position	0-50 km	0.4 km	0.2 km	1 hr
Iceberg or Ice Island Features: Length, Width Height, Draft	0-1000m	±10%	2-5 m	as required
Mass	Best estimate			

*Note: During storms (significant wave height greater than 4m or wind speed greater than 34 knots) continuous recordings should be made of wind speed and direction and wave height and period.

Parameter	Depth	Range	Accuracy	Resolution	Frequency
Current Direction		0 - 360°	±5°	5.0°	1 hr or 20 min.
Current Speed	a) 20m	5-250cm/sec	±3% of full scale	3cm/sec	a) 1 hr
	b) 20m	5-250cm/sec	"	2cm/sec	b) 20 min
	c) Mid depth	5-250cm/sec	"	2cm/sec	c) 20 min
	d) 20 m from bottom	5-250cm/sec	"	2cm/sec	d) 20 min
	a) is for Type 2 measurements b),c)+d) are for Type 3 measurements				
Water Temperature	Same as for Currents	-2 to 25°C	±0.2°C	0.1°C	Same as for Currents
Salinity (Conductivity)	Same as for Currents	0-36o/oo	±0.2o/oo	0.1o/oo	Same as for Currents
Tides (Pressure)	Bottom	0-250 m	0.01% of full scale	0.002% of full scale	1/2 hr
Turbidity (Underwater Visibility)	Bottom	Visual estimates from well head TV camera			

Please note that the above specifications relate to most areas but due to the variability of physical environmental conditions from place to place a particular well location may dictate different specifications. It is paramount that operators discuss their plans for a measurement program with the appropriate authorities before purchasing or loaning equipment.

Parameters to be Reported

All standard meteorological parameters (i.e parameters from a) to k) in the list on page 2) need to be transmitted to the Atmospheric Environment Service (AES) at least every three hours. Hourly and Special meteorological observations are required in support of aviation operations (see page 12) and local tactical ice forecast services. In any event, operators are encouraged to take and transmit hourly observations at all times.

Sampling Frequency During Storms

When the significant wave height exceeds 4m or the average wave speed is greater that 34 knots wind and wave parameters are to be recorded as near to continuous as possible.

Description of the Measurement Program

A description of the physical environmental program must be submitted with the description of the drilling program. The following details are required:

a) instrumentation - make, model, specifications, location of spares;

b) mounting location and arrangements - height, distance to obstructions;

c) mooring or deployment arrangements - depth of instruments, buoys, etc. include a detailed sketch indicating all components;

d) recording system - equipment, sampling frequency, format, etc.;

e) calibration procedures - frequency of calibration;

f) maintenance schedule;

g) disposition of data - approximate time recorded data (tape format) will be supplied to the appropriate regulatory agency;

h) name and address of any consultants involved in the program.

Installation, Maintenance and Monitoring

Officials of AES and OSS (see Table 2 and 3) responsible for the area of operation should be consulted on the installation of equipment in order to ensure optimum positioning of the instruments. Actual installation and maintenance of the equipment is to be the responsibility of the drilling operators. Inspection trips by AES and OSS will be coordinated with the operators through the Conservation Engineers. The observing programs aboard the drilling units and any ancillary vessels which may be equipped as a weather observation platform, will be monitored by the staffs of operational AES offices receiving the weather reports and by the Regional Director in the respective AES Region. Quality control actions at AES Downsview prior to archiving will also serve to monitor the overall operation. The oceanographic observation program will be monitored by OSS. Quality control actions at MEDS prior to archiving will also serve to monitor the overall oceanographic program.

Table 2

ATMOSPHERIC ENVIRONMENT SERVICE CHIEFS OF DATA ACQUISITION

Region	Address	Telephone No.
Atlantic Region	Regional Director Atmospheric Environment Service 1496 Bedford Highway Bedford, N.S. B4A 1E5	902-835-9328
Quebec Region	Directeur Régional Service de l'Environnement Atmosphérique 100, Boul. Alexis Nihon Troisième étage Ville St-Laurent Province de Québec H4M 2N6	514-333-3000
Ontario Region	Regional Director Atmospheric Environment Service 25 St. Clair Ave., East Toronto, Ontario M4T 1M2	416-966-5624
Central Region	Regional Director Atmospheric Environment Service Room 1000 266 Graham Ave. Winnipeg, Manitoba R3C 3V4	204-949-4380
Western Region	Regional Director Atmospheric Environment Service Argyll Centre 6325 - 103 Street Edmonton, Alberta T6H 5H6	403-437-1250
Pacific Region	Regional Director Atmospheric Environment Service Suite 700, 1200 West 73rd Ave. Vancouver, B.C. V6P 6H9	604-732-4673

Table 3

OCEAN SCIENCE AND SURVEYS SERVICE ADVISORS

Region	Address	Phone No.
All Regions	Director Marine Environmental Data Service 240 Sparks St., 7th Floor Ottawa, Ontario K1A 0E6	613-995-2007
Atlantic and Eastern Arctic	Marine Advisory & Industrial Liaison Office Bedford Institute of Oceanography P.O. Box 1006 Dartmouth, N.S. B2Y 4A2	902-426-3698
Gulf of St. Lawrence River	Director, OSS Dept. of Fisheries & Oceans P.O. Box 15500 901 Cap Diamant Quebec, P.Q. G1K 7X7	418-694-7781
Hudson and James Bay	Chief, Oceanography Division OSS Central Region P.O. Box 5050 Canada Centre for Inland Waters Burlington, Ontario L7R 4A6	416-637-4380
West Coast and Western Arctic	Chief, Ocean Information Services Division Institute of Oceanographic Sciences Pat Bay, B.C. V8L 4B2	604-656-8217

Training

The staff members taking these physical environmental observations on drilling units or support vessels must have successfully completed a training course dealing with the procedures for making, recording and reporting marine meteorological and oceanographic observations. Arrangements for such training sessions, can be made through the Regional Director in the respective AES Region having marine responsibility and through the Director of MEDS. These training sessions serve to ensure reasonable standardization of observing practices, coding and reporting procedures. Observers who are inactive for an extended period may require retraining.

Recording of Observations

Physical environmental observations are to be recorded in a "Meteorological and Oceanographic Log" according to the observational practices and coding of weather data procedures described in MANMAR and SAWR. These log books are furnished by AES through the Regional Director. When completed, the logs are to be sent to the Regional Director in the respective AES Region for quality control. All meteorological observations will be archived with AES, Downsview. The AES Regional Director will forward the oceanographic part of the log to MEDS to be checked for quality control and subsequent archival. Operators are expected to keep a separate log of hourly iceberg and /or ice island positions and characteristics. This log and a magnetic tape copy will be sent to the appropriate regulatory agency at the end of the drilling season. Operators are asked to make every attempt to have all parameters and data recorded on magnetic tape. In most cases different magnetic recorders will be used for different parameters but attempts should be made to reduce the number of tape recorders to a minimum. Copies of the magnetic tape records are to be submitted in computer-compatible format with the final well report.

All logs are subject to inspection during on-site visits by the Conservation Engineers and possibly AES or OSS officers.

FORECAST SERVICES

Two types of forecast services are normally required in support of drilling operations in the Canadian offshore. One, the Site-Specific Forecast Service, is for normal and emergency conditions related to drilling operations. The second is the Aviation Weather Forecast Service, for support flights. Other forecast services are required in areas affected by ice.

Site-Specific Forecast Service

The operator will be required to provide a site-specific weather and sea state forecast service in support of offshore drilling operations. It should be designed to meet the needs of both normal and emergency operations and should be at least equivalent in quality and accuracy to the regional services normally provided by the AES.

The forecast should be prepared by qualified meteorologists familiar with the AES core forecast guidance, practices and procedures and should be consistent with the AES core service for the area. If major differences appear warranted, the forecaster providing the site-specific service should consult with the appropriate AES forecaster and attempt to resolve the differences. Any AES Weather Warning in effect for the drilling areas must be mentioned.

The forecasts should be based on the AES core guidance material available in real time from the appropriate AES regional forecast centres. The emphasis in these site-specific forecasts needs to be placed on an increased spatial and temporal resolution of the core guidance material using all appropriate information and facilities. Continuous monitoring of the weather, wave and ice systems will be needed to ensure that updates are made as required.

Specific requirements for this site-specific forecast service are given below:

a) Forecasts are to be issued at least every twelve hours with a 6 hour manditory update or more frequently as required. A continuous weather watch must be maintained at the special forecast office 24 hours per day;

b) Forecasts are to include wind speed and direction; sea state (wave height, period and direction for both sea and swell); precipitation; visibility; sky condition; air temperature; a synopsis of present weather patterns and when appropriate, freezing spray and ice conditions;

c) Forecasts are to extend over a 48-hour period, with emphasis on the first 12 hours;

d) Weather outlooks are to cover 48 to 120 hours;

e) Weather warnings are to be issued as required and the appropriate AES Weather Center notified;

f) In case of an emergency, special forecasts tailored to the emergency, and frequently updated, are required;

g) Meteorologists on the forecast team are to meet AES standards for training and experience; at least half of the forecasters should have had substantial experience with AES core guidance material;

h) The forecast team should have some professional forecast experience in the geographical region;

i) Acceptable forecast quality and accuracy may require the addition of observation stations to the present network, particularly upstream from the forecast point;

j) An effective data communications system is required to ensure the timely transmission and receipt of environmental data and forecasts in near real-time;

k) Canadian firms are to be used to the greatest extent practicable for private forecast services;

In the event of an emergency, extra services will likely be needed. Both AES and the company forecasters and observers should be prepared, and familiar with the requirements of the operator's contingency plans.

Aviation Weather Forecast Services

The Department of Transport (DOT) may require that an aviation weather forecast be available for any aviation service needed for drilling program support. In those areas where the Canadian Air Transport Administration formally identifies a requirement for aviation site-specific aerodrome forecasts, these will normally be provided by AES. Under these conditions, the operator is responsible for operating a meteorological observing program that supports the forecasts. To ensure that this program meets the objectives and standards established by AES, operators will be expected to enter into a formal agreement with AES. Additional information can be obtained from the Regional Director in the appropriate AES Region.

Pack Ice Forecast Services

In areas where drilling operations are conducted in pack ice, a local tactical ice forecast service will be required. To support this service, aerial reconnaissance and hourly meteorological and oceanographic observations will be required in addition to the ice parameters observed from the drilling platform. Forecasts are to extend over 24 hours, with emphasis on the first 6 hours, and should be prepared by qualified personnel.

The forecast will be issued and updated as the ice situation dictates.

Iceberg or Ice Island Trajectory Forecast Service

When drilling operations are conducted in areas of drifting icebergs or ice islands a local tactical iceberg or ice island trajectory forecast service will be required. At least every three hours qualified personnel should make an estimate of the time and point of closest approach for each iceberg or ice island in radar range.

Environmental Data Analysis and Summary Report

As part of a well history report operators are to provide a summary of weather, ice conditions, and sea-state. This summary should include among other things the following:

a) time series plot of the three-hourly wind speed and direction, significant wave height, zero-crossing wave period, wave period at the peak of the wave spectrum, current speed and direction (using hourly values) and air and sea temperatures;

b) monthly minumum, average and maximum values of all parameters observed or measured;

c) monthly histograms of visibility and ceiling conditions relating to the various aircraft operating limits, swell wave direction, ice thickness, ice floe size, ice floe speeds, ice ridge height and keel depth, iceberg or ice island length, height, mass, draft and drift;

d) monthly joint histograms (scattergrams) of the following (indicate the actual number of observations);

i) wind speed versus direction;
ii) significant wave height versus wind speed;
iii) significant wave height versus zero crossing wave period;
iv) significant wave height versus peak wave period;
v) significant wave height versus predominant wave direction;
vi) current speed versus direction;
vii) persistence of wind speed versus speed;
viii) persistence of current speed versus speed;
ix) persistence of wind direction versus direction;
x) persistence of significant wave height versus height;
xi) persistence of current direction versus direction;
xii) persistence of visibility versus range;
xiii) iceberg or ice island drift speed versus mass;
xiv) iceberg or ice island drift speed versus draft;

e) detailed analysis of major storms, and drilling unit motions particularly if they led to waiting-on-weather, an accident or damage to equipment;

f) general description of the variability in the near-bottom water turbidity (underwater visibility);

g) assessment of data quality, instrumentation, data gaps, etc.;

h) a description of any modifications made to the original measurement or recording plans as submitted to the regulatory agency;

i) recommendations for change in any future measurement programs;

j) a verification of the weather, ice and sea state forecast services.

Subsequent to the submission of this summary operators must also submit a computer-compatible tape or tapes of all data recorded. These tapes must be in 9-track, 1600 bpi format and should be submitted to the appropriate regulatory agency with documentation on calibrations and conversions to engineering units.

NORDCO LIMITED

P.O. BOX 8833 ST. JOHN'S NEWFOUNDLAND,CANADA. AIB 3T2 TELEPHONE (709) 364-1200 TELEX 016-4596

POOR

QUALITY

ORIGINAL